Pasture regeneration and gorse seedling control in the Port Hills following fire

A dissertation/thesis

submitted in partial fulfillment

of the requirement for the Degree of

Bachelor of Agricultural Science

at Lincoln University

by

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Lincoln University

2017

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This dissertation examined the regeneration of pasture after a fire and the control of gorse seedlings using Italian ryegrass competition and herbicides. The experiments were run at a property on the Port Hills, Canterbury which had areas of gorse and brown top dominant pasture burnt in the fires of February 2017. The experiment ran from 17 March 2017 to 3 October 2017. Pasture growth rates were higher in burnt pasture (6.3 kg DM/ha/d) compared with unburnt pasture (4.4 kg DM/ha/d). Subterranean clover seedling establishment ranged from 37.5 plants/m^2 in the unburnt pasture to 648 plants/m^2 in the burnt pasture. This was due to the heat from fire breaking the subterranean clover hard seed. The fire also removed resident pasture material allowing greater light interception by the seedlings. The burnt gorse area was oversown with an Italian ryegrass pasture mix in March. Gorse seedling numbers were reduced by 52% in plots sown with Italian ryegrass compared with unsown plots. On the 3 October 2017 there were >400 gorse seedlings/m^2 in areas with Italian ryegrass. Other control methods, such as grazing, will need to be used to further reduce the gorse population. There were more gorse and grass seedlings and fewer subterranean clover seedlings on the south slope of the gully compared with the north slope. This was due to greater soil moisture on the south slope favouring the growth of Italian ryegrass and gorse. Thus, subterranean clover was outcompeted due to shading.

The effect of eight herbicide treatments on gorse seedlings were visually assessed using the EWRS rating system. Herbicides were applied in August or September. Treatments including saflufenacil gave initially gave faster results but at the end of the experiment there was no difference between saflufenacil treatments and the single herbicide treatments. Glyphosate was the most effective herbicide at both application dates but also damaged the grass seedlings. Terbuthylazine was only effective when applied in September as it is root absorbed. Faster results were seen in all treatments when applied in September compared with August. This is due to higher growth of the plants in spring.

The removal of mature gorse bushes by the February 2017 fire created on opportunity to control the gorse population on the Port Hill, Canterbury. This research shows that Italian ryegrass competition will not eliminate the gorse population and other methods, such as grazing, should be used in conjunction. Pasture that was burnt has regenerated well and should also be grazed to reduce the fire risk and to retain subterranean clover.

Keywords: gorse, *Ulex europaeus*, Italian ryegrass, *Lolium multiflorum*, subterranean clover, *Trifolium subterraneum*, competition, biological control, chemical control, fire, pasture regeneration, hill country, aspect

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1 INTRODUCTION

On the 13th February 2017 a major fire started in grasslands on the Port Hills of Christchurch. The fire started on Early Valley Road with a second fire starting a few hours later on Marleys Hill. The two fires had merged by the 15th February. It took two weeks for firefighters to control 99% of the fire which was officially extinguished on the 20th April, three months after it started (The Press, 2017). The fire burnt 1645 ha of land, including pastures, native bush, 11 houses and two outbuildings. The cause of the fires are currently unknown, with investigations ongoing, but the second fire, on Marleys Hill, is considered suspicious. The Early Valley Road fire is thought to have started due to faulty powerlines but this is disputed by the lines company (Stuff, 2017).

The Port Hills is a peri-urban environment containing a mix of life style blocks, farmland, pine forests and recreational reserves. The area is laxly grazed by sheep and cattle or not grazed at all, leading to a build up of dead material and seedheads over summer (Moot, 2017). The north west wind causes the dead grass to dry out even more. A wet spring prior to the fire resulted in higher herbage growth than usual which coupled with the lax grazing lead to a large amount of biomass. The dead material and large amounts of gorse on the Port Hills also contributed to the spread of the fire. This, combined with steep terrain, made it difficult to control.

After the fire, Professor Moot of Lincoln University was approached by a group of landowners to consider options for regeneration of pastures after the fire. Specific concerns were initially related to the recovery of the burnt pasture area. This was expected to require resowing before autumn. However, inspections of the pasture indicated a mass of subterranean clover was germinating following rainfall about 10 days prior (Moot, personal communications). The decision was made not to oversow, but allow natural regeneration of the pasture. One of the property owners allowed access to their land for the ongoing monitoring of herbage recovery which is reported in this project. This provides a rare and unique opportunity to examine how pastures and gorse recover after fire in a peri-urban environment.

The property used in this study was off Early Valley Road, near where the first fire started. The site consists of a pasture that had been laxly grazed by cattle and a steep gully that had been covered in gorse (*Ulex europaeus*) for many years. The pasture was browntop (*Agrostis capillaris*) dominant with some perennial ryegrass (*Lolium perenne*) and clovers. Most of the pasture area was burnt. However, an area of pasture by the house was completely unburnt due to firefighting efforts to save the house. This pasture was ~0.3 m tall with dead seedheads, typical of the area that did burn. The seedheads and dead material in the pasture would have contributed to the quick spread of the fire because fires in tall grass are reported to move four times faster than fires in well grazed pastures as they have less green material and more fuel (Cheney, 2009). The gorse area was completely burnt in the fire as gorse is one of the most flammable plant species (Wyse *et al.*, 2016). Gorse is easily burnt even when green due to volatile oils present in the spines. The fences on the property were all burnt so remediation was taken without an expectation of being able to use grazing stock.

The aim of this dissertation is to describe pasture regeneration of burnt hill country and from this determine methods to control emerging gorse seedlings following a fire. To do this there are four main objectives of this dissertation:

1. To measure pasture regeneration after a fire, focusing on subterranean clover (*Trifolium subterraneum*) populations and changes in botanical composition.
2. To quantify the regeneration of gorse seedlings from a burnt gorse stand and determine if oversown pasture can decrease gorse seedling survival.
3. To quantify gorse seedling regeneration and the establishment of oversown pastures on north and south facing slopes.
4. To identify which herbicide was most effective in killing gorse seedlings.

To investigate these objectives transects were marked out in areas of pasture that had different levels of burning to measure pasture regeneration. Plots and transects were also marked out in a burnt gorse area oversown with an Italian ryegrass (*Lolium multiflorum*) pasture mix to quantify regeneration of gorse seedlings and the effectiveness of Italian ryegrass competition as a control. Eight different herbicide treatments were applied to determine which results in the most damage to gorse seedlings.

2 REVIEW OF THE LITERATURE

2.1 Introduction

This literature review covers the influence of aspect on pasture production and composition of hill country pasture in New Zealand. This is because the resisdent vegetation of pasture was on a west facing slope. In contrast, the gorse was established on a steep north and south facing gully area. The review will also examine the biological and chemical control options for gorse seedlings.

2.2 Hill country pastures

2.2.1 Aspect and climate

Aspect has a large influence on hill country pastures. Aspect can influence factors such as rainfall, temperature and evapotranspiration which then affect pasture production and composition. Radcliffe & Lefever (1981) measured the differences between north and south facing slopes for rainfall, temperature and soil moisture over five years on hill country in North Canterbury. As expected, there was no difference in rainfall between the two aspects. However, the north slope had a higher mean daily air temperature of 13.7°C compared with 9.9°C on the south side. The major difference between the aspects was transpiration which totaled 1360 mm/yr on the north slope and 698 mm/yr on the south (Table 2.1). The north slopes typically had higher mean daily transpiration rates in every month. There are no similar studies of Banks Peninsula but it is likely these environmental differences are indicative of what could be found at the location of the current study.

Table 2.1 Daily mean evapotranspiration (mm) on north and south aspects in North Canterbury (Radcliffe & Lefever, 1981).

	North	South
January	4.7	4.1
February	5.0	3.3
March	4.3	1.8
April	3.5	0.7
May	2.7	0.1
June	1.9	<0.1
July	2.4	<0.1
August	2.6	0.3
September	2.6	0.9
October	4.2	2.5
November	5.0	4.0
December	5.9	5.3
Total	1360 mm/yr	698 mm/yr

2.2.2 Pasture production

Hill country pasture production is dependent on factors such as climate, soil fertility, plant species and aspect (Radcliffe, 1982). Annual pasture accumulation on a hill country site in Oxford ranged from 3.5 – 7.4 t DM/ha depending on year and slope aspect (Table 2.2). Based on a four year average, the south facing slope produced more (0.7 t DM/ha/yr) than the north facing slope. Although temperatures were higher on the north facing slopes, growth was limited due to decreased soil moisture. This is especially evident in summer. Phosphate was also limiting growth on both aspects in this experiment. Whether the north or south slope produces more depends on the balance of rainfall and evapotranspiration.

Table 2.2 Annual pasture accumulation (t DM/ha) on north and south facing aspects in Oxford, Canterbury (Radcliffe, 1982).

Aspect	1973/74	1974/75	1975/76	1976/77	Average
North	3.5 $_b$	5.5 $_b$	5.7 $_b$	6.6 $_a$	5.3 $_b$
South	3.7 $_a$	6.3 $_a$	7.4 $_a$	6.6 $_a$	6.0 $_a$

2.2.3 Botanical composition

Hill country pastures are typically dominated by low fertility grasses such as browntop (Grant & Lambert, 1979). Legume content is usually low, due to low phosphorous levels in hill country soils. Phosphorous uptake by legumes is further limited due to strong competition with browntop (Jackman and Mouat, 1970). Higher levels of perennial ryegrass are found in pastures that have been fertilised. Subterranean clover is more suited to hill country pastures as it is usually too dry for white clover (*Trifolium repens*), particularly on north facing slopes. Subterranean clover also has earlier spring growth so suits summer dry environments.

Botanical composition of hill country pastures is also affected by aspect. South facing slopes tend to be cool and wet, which favours browntop, compared with north facing slopes that are warm and dry. This is because north facing slopes experience higher evapotranspiration rates compared with south facing slopes, as shown in Table 2.1, due to their exposure to NW winds (Radcliffe & Lefever, 1981). Slope effects were investigated in hill country pastures at Ballantrae, Palmerston North (Lambert *et al.,* 1986). Botanical composition was estimated from herbage samples taken from east, south-west and north-west facing slopes six times a year. Five catergories were used to make up the botanical composition; ryegrass, high fertility responsive (HFR) grasses such as cocksfoot (*Dactylis glomerata*), low fertility tolerant (LFT) grasses such as browntop and sweet vernal (*Anthoxanthum odoratum*), legumes and other species. Ryegrass and HFR grass content was higher on SW slopes than NW slopes (Figure 2.1). Legume content was higher on the NW slopes than the SW slopes. There was no difference between NW and SW facing slopes in terms of other species and LFT grasses. LFT grasses were the largest component of all three slopes making up around 60% of the pasture. Perennial ryegrass was less prevalent on north facing slopes as they were drier. This allowed an increase in legume content as there was less competition with grass. Browntop is tolerant of low fertility and a range of climates which is why it dominates on both aspects.

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Figure 2.1 Aspect effects on pasture botanical composition (% DM). Average values for 1972-1981. HFR - high fertility responsive, LFT - low fertility responsive (Lambert *et al*., 1986).

2.2.4 Soil fertility

Hill country soils are typically low in nitrogen and phosphorous and have historically been fertilised with superphosphate to increase legume growth. Legumes are used to provide biological N fixation but legume growth is limited in low phosphorous soils. Clover is very responsive to phosphate fertiliser, increasing by 795 kg DM/ha/yr when Olsen P was increased from 9 to 28 (Gillingham *et al.,* 1998). The legume then provides more nitrogen for the grasses. Phosphate levels are low in hill country soils due to fertility transfer by stock (Gillingham & During, 1973). The majority of phosphorous is deposited on stock camps on flatter areas of the slope. The land used in this experiment had not been fertilized for many years (David Scheil, personal communications). This mean the lack of phosphorous probably affected clover growth on both the pasture and gorse areas.

2.2.5 Oversowing hill country pastures

Oversowing is the only way to improve pastures on hill country that is too steep to cultivate. Sowing rates used for oversowing are typically higher than other pasture renewal methods as establishment rates are low. Chapman *et al.,* (1985) measured the germination and seedling survival of perennial ryegrass, cocksfoot and white clover oversown onto hill country. Plots were sown with either perennial ryegrass (32 kg/ha) and white clover (3 kg/ha) or cocksfoot (14 kg/ha) and white clover (3 kg/ha). Plots received one of five different treatments prior to oversowing in spring. The treatments were lax grazing, hard grazing, blanket spray with paraquat, blanket spray with glyphosate and blanket spray with glyphosate followed by hard grazing. The plots were hand sown on the 23 September 1981. Seedling appearance was assessed every three to four days until 30th October and then every seven days until 25th November. The final seedling appearance of the grasses was 33% of the total sown seed (Figure 2.2). Seedling emergence was initially faster for ryegrass in the first 24 days compared with cocksfoot. White clover seedling appearance was 58% of the seed sown. Seedling appearance was 15% lower in the laxly grazed plots for both grasses compared with the other four treatments that were not significantly different (Chapman *et al.*, 1985). For white clover, the two treatments with hard grazing resulted in the highest seedling appearance and the paraquat and glyphosate treatments resulted in the lowest seedling appearance. The authors did not explain this finding but it is possible that the herbicides may have removed all herbage cover which mean seedlings were exposed to dessication.

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Figure 2.2 Mean seedling appearance (cumulative % of seeds sown) of ryegrass (□), cocksfoot (Δ), and white clover (○). Significant differences between ryegrass and cocksfoot are indicated where they occur as * = $p<0.005$, *** = $p<0.001$ (Chapman *et al.*, 1985).

Hard grazing results in more bare ground resulting in less competition between emerging seedlings and the previous pasture (Chapman *et al.*, 1985). It also makes it more likely for seed to fall onto the soil instead of onto existing plants. Herbicides create the same effect. Reasons for seeds not to germinate include the seed becoming non-viable or dormant or through predation. After the Port Hills fire all of the existing gorse vegetation was burnt leaving bare ground prior to oversowing. This should lead to high levels of establishment of the oversown pastures which will be quantified in this dissertation.

The success of subterranean clover establishment after oversowing is variable depending on climatic conditions. Subterranean clover establishment following oversowing in two different temperatures and soil moisture levels was investigated by Awan *et al.* (1993). Warm treatments were sown in March (Warm-Dry) and April (Warm-wet) and the cool treatments were sown in June in Hastings. The cool-dry treatment was sown two weeks later than the cool-wet treatment. Existing vegetation was sprayed with glyphosate and mown prior to oversowing. Up to 80% of sown subterranean clover seed failed to establish. A higher number of seedlings established in the warm treatments, with 54 plants/m^2 in the warm-dry treatment compared with 23 plants/m^2 in the cool-dry treatment 120 days after sowing (Table 2.3). Establishment was also slower in the cool treatments with no emerged seedlings 30 days after sowing. The warm-wet treatment initially had around 50 fewer plants/m^2 compared with the warm-dry treatment but 120 days after sowing this difference had reduced to 8 plants/m^2.

Table 2.3 Subterranean seedling number (plants/m^2) over time in cool and warm seasons and wet and dry soil conditions (Awan *et al.*, 1993).

Days after sowing	Cool-Dry	Cool-Wet	Warm-Dry	Warm-Wet
30	0	0	152	106
75	23	1	75	53
120	23	1	54	46

The germination of subterranean clover seeds is higher when the seed is buried (Yates, 1957). This could explain why most seed did not establish when oversown. The seedlings germinate faster in warmer conditions due to the more rapid accumulation of thermal time. The growth of the existing pasture would be higher in the wet treatment so there would be more competition for emerging subterranean clover seedlings. The average annual rainfall for the site used by Awan *et al.* (1993) was 771mm which is similar to the 30 year average for Lincoln. This means the subterranean clover oversown in this experiment may be establish better on the north facing slope compared with the south facing slope as it would be warmer and drier.

2.2.6 Thermal time requirements for germination and emergence

Thermal time is a measure of cumulative temperature that can be used to predict points in development of a plant (Moot *et al.*, 2000). It is a better indicator of the rate of development than chronological time, as temperatures can vary between seasons and years. Plant development starts when the temperature reaches a base temperature (T_b). The rate of plant development increases as the temperature reaches an optimum (T_o). As temperature rises above T_o the rate of plant development slows and eventually stops. This temperature is the maximum temperature (T_m). The calculation of thermal time is commonly done using sub-optimum temperatures, between T_b and T_o. This is because temperate climates rarely exceed the maximum temperature (Black *et al.,* 2006).

Moot *et al*. (2000) reanalysed data by Charlton *et al.* (1986) and Hampton *et al.* (1987) to quantify thermal time to germination of different grass and clover species. Field emergence of the grass and clover species was also investigated in a trial at Lincoln. The thermal time requirement for germination was lowest for subterranean clover (45°Cd) and highest for cocksfoot (210°Cd) (Table 2.4). Subterranean clover also had the lowest thermal time requirement for emergence of 120°Cd. Italian ryegrass had the highest shoot dry weight (379 mg) 57 days after sowing in March. This was much higher than the shoot dry weight of cocksfoot (34.5 mg) at the same time suggesting that Italian ryegrass has a faster growth rate.

Table 2.4 Thermal time to 75% germination, 50% emergence and shoot dry weight 57 days after sowing on the 21/03/1996 for different grass and clover species (Moot *et al*., 2000).

Species	Germination (°Cd)	Emergence (°Cd)	Shoot dry weight (mg)
Italian ryegrass	90	145	379
Perennial ryegrass	90	160	176
Subterranean clover	45	120	209
Cocksfoot	210	250	34.5

The emergence of cocksfoot in this dissertation may be slow due to declining soil temperatures, as it was sown in March (Moot *et al*., 2000). It may be outcompeted by Italian ryegrass as it has a lower thermal time requirement and faster growth rate. Establishment of the pasture may be quicker on the north slope as the temperature will be slightly higher compared with the south.

2.3 Effect of fire on gorse seed

Burning is one of the easiest ways to remove mature gorse plants and is commonly used in forestry (MacCarter and Gaynor, 1980). However, the heat from the fire can stimulate the germination of gorse seeds in the soil. Zabkiewicz and Gaskin (1978) showed that the number of days to final germination was not decreased until temperatures reached over 100°C (Table 2.5). Heating at temperatures between 60-80ºC resulted in the quickest germination time of 10 days compared with the control treatment which took 17 days to germinate. The seeds were heated either in an oven (dry heat treatment) or in a water bath (wet heat treatment) before germination. Heating of the seeds allows an increased rate of water uptake leading to a faster germination rate (Zabkiewicz and Gaskin, 1978). Maximum post-fire temperatures of a wildfire in summer in Australia were 40ºC for the top 4.5 cm of soil and 60°C for the top 0.5 cm of soil (Auld and Bradstock, 1996). The majority of gorse seed is typically found in the top 5 cm of soil (Ivens, 1978). This means that following the fires on the Port Hills, gorse seed could be expected to germinate in as few as 10 days. Competition from pasture and herbicides will be used in this experiment to determine whether they can provide effective control of the rapidly germinating gorse seedlings.

Table 2.5 Effect of wet or dry heat on gorse seed germination. Seeds were heated for 10 minutes (Zabkiewicz & Gaskin, 1978).

	Days to final germination	
Temperature (°C)	Dry heat	Wet heat
150	60	-
100	14	15
80	10	10
60	10	8
16	17	-

2.4 Biological controls

There are several biological controls that have been proposed as a method of gorse control. These include competition with other plant species, grazing/defoliation and insect biocontrol agents. Of these, competition is likely to be the only option for this study because there is no longer fences or infrastructure for grazing at the site.

2.4.1 Ryegrass competition

Competition from perennial ryegrass can slow gorse seedling growth. In a glasshouse trial conducted over 22 weeks perennial ryegrass, 'Grasslands Nui', and gorse seed were sown at five different ratios (1:0, 0.75:0.25, 0.5:0.5, 0.25:0.75, 0:1) in wooden boxes, 30 cm^2 by 20 cm deep (Ivens and Mlowe, 1980). There were three grass defoliation treatments (uncut, cut to 2 cm above soil, cut to 4 cm above soil) with the first defoliation occurring 10 weeks after sowing and then every four weeks thereafter. As the amount of ryegrass in the mix increased the percentage of gorse in the total shoot dry matter decreased. In the first harvest the percentage of gorse dropped from 9.1% in the 0.75:0.25 gorse:ryegrass mix to 2.1% in the 0.25:0.75 treatment (Table 2.6). This difference increased in the following harvests with a gorse percentage in the third harvest of 29.9% in the highest gorse ratio treatment compared with 9.4% in the lowest gorse ratio treatment. These results are consistent with Davies *et al.* (2005) who found perennial ryegrass sown at 15 kg/ha significantly reduced gorse seedling shoot DW from around 23 g in the control to 2 g in the ryegrass treatments (Figure 2.3). Ryegrass competition reduced shoot dry weight more than the gorse thrips (*Sericothrips staphylinus*) and grazing treatments in the same experiment. Ryegrass competition did not result in the death of gorse seedlings in either experiment (Ivens and Mlowe, 1980; Davies *et al.*, 2005). Gorse competes poorly with grass due to grass tiller development which occupies the soil surface resulting in shading and a lack of space for the gorse seedlings (Ivens and Mlowe, 1980). As a result, the gorse has a reduced photosynthetic rate and therefore reduced growth. A fast establishing grass is necessary to compete with gorse seedlings that emerge quickly hence why the use of Italian ryegrass in this dissertation.

Table 2.6 Gorse as a percentage of total shoot dry matter over three cutting periods. Percentages are an average of the two cutting heights (Ivens & Mlowe, 1980).

Weeks after sowing	Plant ratio (gorse:ryegrass) 0.75 : 0.25	0.5 : 0.5	0.25 : 0.75	LSD between plant ratios (P = 0.05)
14	9.1	3.9	2.1	2.0
18	15.4	6.9	3.6	5.6
22	29.9	18.0	9.4	4.3
Total harvest	17.9	11.9	6.2	4.2

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Figure 2.3 Shoot dry weight of gorse seedlings exposed to three treatments, gorse thrips (T), grazing (G) and ryegrass competition (R) (Davies *et al.,* 2005).

2.4.2 Grazing control of gorse

Grazing is another method that can be used to suppress gorse seedling growth. A study of grazing management comparing gorse control by sheep and goats in North Canterbury found all treatments involving goats, apart from set stocking of sheep + goats, reduced gorse cover (Radcliffe, 1985). Dense gorse plants had been previously burnt then sown with perennial ryegrass and white clover two months before grazing began. Both the goat only treatments and set stocked sheep + goat treatment resulted in a gorse cover close to 1% compared with the sheep only treatments that were as high as 50% gorse cover (Figure 2.4). This is likely to be due to differences in sheep and goats grazing styles. Goats remove most of the green material on the gorse which restricts photosynthesis. They also ring bark mature stems which deplete gorse root reserves decreasing the growth of the gorse (Radcliffe, 1985). Grazing combined with ryegrass competition has shown greater mortality rates than ryegrass competition alone (Figure 2.5). However, grazing was unable to be used as a control method in the current study as the fences on the property had burnt in the fire and have not yet been replaced.

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Figure 2.4 Gorse cover (%) under different grazing managements of sheep and goats. ○ – sheep, △– goats, ▲– goats and sheep, solid line – set stocked, dashed line – rotation (Radcliffe, 1985).

2.4.3 Biological control of gorse using insects

Several insects and mites have been released into New Zealand as biological controls for gorse. Gorse seed weevil (*Exapion ulicis*) was the first biological control to be released in 1931 and a further six species were released in the early to mid-1990s. Gorse seed weevil, gorse spider mite (*Tetranychus lintearius*), gorse thrips and gorse pod moth (*Cydia succedana*) are now widely established throughout New Zealand (Hill *et al.*, 1999). However, insect controls are largely ineffective and require other methods, such as grazing or competition, to kill gorse seedlings (Figure 2.5). The density of gorse in the patch that burnt, which is the study area, suggests these insects were either not operating or ineffective as a control method. They are unlikely to provide any control of the emerging gorse seedlings.

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Figure 2.5 Seedling mortality of gorse exposed to three treatments, gorse thrips (T), grazing (G) and ryegrass competition (R) (Davies *et al.,* 2005).

2.5 Herbicides

There are several herbicides available that are used to control gorse seedlings and are mainly used in the forestry industry as a pre-treatment. This dissertation will focus on the effectiveness of these herbicides in a pastoral situation.

2.5.1 Picloram and triclopyr

Picloram and triclopyr have both been found to effectively control gorse seedlings. For example, different herbicides were treated on new infestations of gorse in Western Australia (Moore and Kennewell, 2010). It was not reported how big the gorse seedlings were. However, gorse sprayed in December was measured 10 months later. Triclopyr killed 98% of gorse plants and an aminopyralid + picloram + triclopyr mix gave 100% control (Table 2.7). Picloram and triclopyr have also been shown to give 100% control of mature gorse bushes 0.5-1.5 m tall as well as preventing cut stumps from re-sprouting (Viljoen and Stoltsz, 2007).

Table 2.7 The control of different herbicides on mature gorse and seedlings 10 months after spraying in Western Australia (Moore and Kennewell, 2010).

Herbicide	Rate	% kill
Aminopyralid + picloram + triclopyr	1000 mL	100
Triclopyr	333 mL	98
Glyphosate	1000 mL	85
Metsulfuron methyl	10 g	95

Picloram and triclopyr are both pyridine derivative herbicides and therefore have a similar mode of action (Cobb and Reade, 2010). Both herbicides have an effect of auxin production. Auxin is a hormone that regulates plant growth through the division, differentiation and elongation of plant cells (Grossmann, 2010). Auxins consist of indole-3-acetic acid (IAA). At low concentrations the addition of synthetic IAAs increases plant growth but damages plants at high concentrations. There are three phases in the plant response to auxin herbicides. In the first phase ethylene synthesis is stimulated, followed by an accumulation of abscisic acid. This results in symptoms such as tissue swelling and stem curling. Root and shoot growth decreases in the second phase along with transpiration, due to stomatal closure, and carbon assimilation. The third phase consists of leaf senescence and wilting leading to plant death. Seedlings that are rapidly growing contain higher levels of auxin which make them more susceptible to auxin herbicides (Cobb & Reade, 2010). Picloram will also kill clover and can affect re-establishment due to residues in the soil which is something to consider if wanting to sow pasture immediately after (Beeler *et al.*, 2004). As both of these herbicides have been found to be effective against gorse seedlings they have been included in this experiment.

2.5.2 Metsulfuron-methyl

Metsulfuron-methyl is a sulfonylurea herbicide typically used for selective weed control in cereals (Cobb & Reade, 2010) but has been shown to control gorse. In the same experiment Western Australia metsulfuron-methyl was applied at a rate of 10 g/1000 l (Moore and Kennewell, 2010). This resulted in the death of 95% of gorse after 10 months (Table 2.7).

Sulfonylurea herbicides, such as metsulfuron-methyl, stop shoot and root growth by inhibiting cell division (Brown, 1990). Visual symptoms include a decrease in growth, chlorosis and necrosis (Blair and Martin, 1988). Metsulfuron-methyl inhibits acetolactate synthase, an enzyme necessary for the synthesis of branched amino acids; valine, leucine and isoleucine (Brown, 1990). Sulfonylurea herbicides have very low animal toxicity as they do not produce branched amino acids. Metsulfuron-methyl also damages both ryegrass and clover at spraying (James *et al.*, 1999). This is something to take into consideration when controlling gorse in pasture and other options such as grazing and/or competition may be preferred.

2.5.3 Terbuthylazine

Terbuthylazine is part of the triazine herbicide family (Cobb & Reade, 2010). Triazine herbicides work by inhibiting photosynthetic pathways. In photosystem II, during photosynthesis, electron transport is blocked (Hirschberg *et al.*, 1984). This results in less photosynthate being produced which leads to chlorosis and necrosis. In a hydroponic study, terbuthylazine killed 100% of gorse seedlings after 30 days (Zabkiewicz *et al.*, 2010). Gorse seedlings were pregerminated and then suspended in a 10.0×10^{-6} M terbuthylazine solution. The effect of application date and gorse seedling size on a terbuthylazine mixture was investigated by Preest (1980). A terbuthylazine + terbumeton + amitrole (TTA) mixture was applied at three different concentrations to gorse seedlings at different growth stages. Three other herbicides, glyphosate, hexazoine and 2,4,5-T were also tested. TTA gave 100% control of gorse seedlings at the first application date, when the seedings were 0.5-1.5 cm tall, at a rate of 2 kg/ha. Gorse seedlings were pregerminated and then suspended in a 10.0×10^{-6} M terbuthylazine solution. The effect of application date and gorse seedling size on a terbuthylazine mixture was investigated by Preest (1980). A terbuthylazine + terbumeton + amitrole (TTA) mixture was applied at three different concentrations to gorse seedlings at different growth stages. Three other herbicides, glyphosate, hexazoine and 2,4,5-T were also tested. TTA gave 100% control of gorse seedlings at the first application date, when the seedings were 0.5-1.5 cm tall, at a rate of 2 kg/ha (Figure 2.6). At the second application date TTA at a rate of 2 kg/ha only killed 20% of seedlings. The seedlings were 1.4-4.0 cm tall at this application. The highest rate of TTA applied only gave 80% control at the second application. When the gorse seedlings were 6-15 cm tall and starting to harden the highest rate of TTA (5 kg/ha) only gave 20% control (Preest, 1980). Terbuthylazine is mostly root absorbed and effectiveness may be influenced by root:shoot ratio (Preest, 1980). The root:shoot ratio declined in summer, along with TTA effectiveness, indicating that the roots were less active at this time. As terbuthylazine is mostly root absorbed less herbicide would be taken up into the plant. Due to the ineffectiveness of TTA on older gorse seedlings, terbuthylazine may only be effective on young seedlings <1.5 cm tall when moisture is present. As there are a lack of field studies on the effectiveness of terbuthylazine used alone against gorse seedlings it is included in this experiment.

Material removed due to copyright compliance

Figure 2.6 Gorse seedling mortality (%) response to four herbicides at two different gorse seedling heights; A = 0.5-1.5 cm and B = 1.5-4.0 cm. TTA - terbuthylazine + terbumeton + amitrole, T – 2,4,5-T, G-glyphosate, H – hexazione (Preest, 1980).

2.5.4 Glyphosate

Glyphosate is a broad spectrum herbicide commonly used to control broadleaf weeds. Lane and Park (1984) investigated the effect of different rates of glyphosate and glyphosate + surfactant mixtures on gorse in New Zealand. The herbicide was applied onto the foliage to the point of run-off onto both soft spine gorse with no flowers and hard spine gorse. The trial was conducted in Northland, Auckland and Wairoa. Results were assessed visually after 12 and 24 months. At the same rate, glyphosate gave greater control of soft spine gorse compared with hard spine gorse (Table 2.8). At a rate of 0.54 kg a.i./100 l there was 96% control of soft spine gorse compared with 67% control of hard spine gorse after 12 months. Gorse in the hard spine stage was harder to wet with herbicide which could contribute to the lower level of control (Lane & Park, 1984). When the gorse spines start to harden and become waxy, absorption through the foliage is harder. Glyphosate is primarily foliage absorbed (Zabkiewicz *et al.*, 2010). Viljoen and Stoltsz (2007) also found glyphosate had poor control of mature gorse when mixed with metsulfuron-methyl, with only 45% control of gorse bushes 0.5-1.5 m tall. Control of soft spine gorse was achieved at rates of 0.54 and 0.72 kg ai/100 l with both rates achieving >95% control after 24 months (Table 2.8). Glyphosate is ineffective against mature plants as uptake is low but is included in this experiment as it had been shown to be effective against gorse seedlings.

The addition of 0.25 g a.i./100 l of Silwet L77, a surfactant, to 0.36 kg ai/100l of glyphosate increased control of soft spine gorse from 62% to 97% after 12 months (Table 2.8). The same treatment also increased control of hard spine gorse from 46% to 97% after 12 months. The addition of Triton X45, a surfactant, also increased control at both gorse stages. Surfactants work by decreasing the tension in the water droplet so it is more spread out onto the leaf. This means a greater surface area of the plant is in contact with the herbicide and therefore the plant absorbs more. Using a surfactant allows lower rates of herbicide to be effective, with 0.18 kg a.i./100 l of glyphosate still giving 88% control of hard spine gorse after 12 months. Surfactants should be used when using glyphosate on hard spine gorse and will also increase effectiveness of glyphosate on seedlings as well.

Table 2.8 Control (%) of different rates of glyphosate and glyphosate mixtures on soft spine and hard spine gorse in the North Island (Lane and Park, 1984).

		Soft spine, no flower		Hard spine	
Treatment	Rate (kg a.i/100 l)	12 months	24 months	12 months	24 months
Glyphosate	0.36	62	80	46	48
	0.54	96	95	67	64
	0.72	90	96	79	81
Glyphosate + Triton X45	0.36 + 0.50	100	-	96	94
Glyphosate + Silwet L77	0.18 + 0.25	87	70	88	71
	0.27 +0.25	-	-	100	87
	0.36 + 0.25	97	95	97	85

2.5.5 Saflufenacil

Saflufenacil is a herbicide of the pyrimidinedione chemical class (Grossmann *et al.*, 2010). Saflufenacil has been proposed for use in forestry as an alternative to older and more harmful herbicides (Zabkiewicz *et al.*, 2010). Zabkiewicz *et al.* (2010) investigated the effect of saflufenacil alone and mixed with other herbicides on gorse. In the first experiment four month old gorse seedlings in pots were sprayed with four rates of saflufenacil (25, 50, 100 and 200 g a.i./ha). The plants were assessed monthly for three months and visually scored on a 1-5 scale with 1 = completely dead and 5 = no effect. A field experiment was also conducted using gorse bushes 1.5-2 m tall. The gorse was sprayed with different rates of saflufenacil plus another herbicide (Metsulfuron-methyl, triclopyr/picloram, glyphosate) in spring. Herbicide damage was visually assessed over a year. Saflufenacil applied alone did not successfully control gorse seedlings.

All rates of saflufenacil applied decreased the gorse health assessment scores three weeks after treatment (WAT) compared with the control, with 200 g a.i/ha being the most effective with a health assessment score of 3.2 (Table 2.9). However, 8 and 11 WAT all treatments had no effect on gorse health. The addition of saflufenacil to metsulfuron-methyl increased brown-out of gorse at all rates compared to metsulfuron-methyl applied alone. The metsulfuron-methyl + 17.5 g saflufenacil treatment resulted in 30% brown-out compared with 0% in the metsulfuron-methyl treatment after 28 days (Table 2.10). After 337 days all metsulfuron-methyl treatments resulted in 80-90% brown-out of gorse. Metsulfuron-methyl is a slower acting herbicide (Viljoen & Stoltsz, 2007) so the addition of saflufenacil provided a more rapid knockdown of the gorse. It is essential to stop gorse seedlings establishing while they are small hence saflufenacil was used in the present study.

Table 2.9 Health assessment scores for gorse at 3, 8 and 11 weeks after treatment (WAT) with saflufenacil. 1 = completely dead, 5 = no effect (Zabkiewicz *et al.,* 2010).

Saflufenacil g a.i./ha	3 WAT	8 WAT	11 WAT
0	4.9 a	5.0 a	5.0 a
25	3.9 b	5.0 a	5.0 a
50	3.6 c	5.0 a	5.0 a
100	3.7 bc	5.0 a	5.0 a
200	3.2 d	5.0 a	5.0 a

The addition of high rates of saflufenacil (3.5 and 7 g a.i./ha) to triclopyr/picloram initially reduced brown-out from 80% in the control to 30% and 50%, respectively (Table 2.10). However, there was no difference in long term effectiveness as all triclopyr/picloram treatments had 100% or close to brown-out after 337 days. This evidence suggests that it is unnecessary to add saflufenacil to triclopyr/picloram when controlling mature gorse bushes. Saflufenacil also increased brown-out of gorse when added to glyphosate by 40-65%. However, there was no advantage after 90 days with glyphosate alone either the same as saflufenacil treatments or within 10%. As these results are from mature gorse bushes, three different saflufenacil mixtures were used in this experiment to see if results are similar in gorse seedlings.

Table 2.10 Mean gorse brown-out (%; 0 = no damage, 100% = no green material) after spraying with saflufenacil plus metsulfuron-methyl, triclopyr/picloram and glyphosate in Canterbury in spring. DAT = days after treatment (Zabkiewicz *et al.,* 2010).

Herbicide (g a.i./100 L)	28 DAT	90 DAT	225 DAT	337 DAT
Metsulfuron-methyl – 9g	0	30	50	80
+ saflufenacil – 0.7g	0	75	90	96
+ saflufenacil – 3.5g	20	60	80	90
+ saflufenacil – 17.5g	30	60	70	90
Triclopyr/picloram – 100g	80	85	90	100
+ saflufenacil – 0.7g	80	90	90	100
+ saflufenacil – 3.5g	30	90	95	99
+ saflufenacil – 17.5g	50	90	95	99
Glyphosate – 540g	0	60	80	90
+ saflufenacil – 0.7g	40	60	80	100
+ saflufenacil – 3.5g	56	70	85	99
+ saflufenacil – 17.5g	65	70	80	95

Saflufenacil reduces plant growth by inhibiting photosynthesis (Grossmann *et al.*, 2010). Activity of protoporphyrinogen IX oxidase (PPO), an enzyme involved in the tetrapyrrole biosynthetic pathway, activity is inhibited (Grossmann *et al.*, 2010). Tetrapyrrole is a compound which plays a role in the function of chlorophyll. Inhibition of PPO also causes the build up of protoporphyrin IX and hydrogen peroxide in leaf tissue which have negative effects on the plant (Grossmann *et al.*, 2010). Hydrogen peroxide levels were shown to increase by 142% in saflufenacil treated velvetleaf (*Abutilon theophrasti*) plants exposed to light compared with plants in the dark (Grossmann *et al.,* 2010). Photosynthesis and chlorophyll production increases when a plant is exposed to light which results in a faster accumulation of hydrogen peroxide and protoporphyrin IX if the plant is exposed to saflufenacil (Grossmann *et al.*, 2010). Zabkiewicz *et al.* (2010) found the initial brown-out of gorse was faster when the herbicide was applied in spring in Canterbury compared with another trial where saflufenacil was applied in autumn in Hawkes Bay. This could be due to the plant photosynthesising and growing more in spring when moisture is available than with autumn. Therefore, saflufenacil should be applied in spring to get more rapid results.

2.6 Conclusions

Pasture production of hill country pastures is higher on south facing aspects compared with north facing aspects. This is due to increased evapotranspiration on north faces. Aspect also influences botanical composition with north faces having higher legume and lower ryegrass content. Hill country soils typically are low in phosphorous which may affect emergence of clovers.

Chemical and biological methods can both give effective control of gorse so are both included in this experiment. Competition with perennial ryegrass alone reduced shoot DW but did not cause any plant mortality. Picloram and triclopyr both gave at least 98% control of gorse seedlings. The effectiveness of metsulfuron-methyl was improved by the addition of saflufenacil. Glyphosate was only shown to be effective on mature gorse with the addition of a surfactant. Terbuthylazine was shown to have 100% control of hydroponic gorse seedlings and to be effective in a herbicide mix but the effectiveness alone in the field is unknown. Effective gorse control strategies must be ongoing for several years due to the longevity of gorse seed in the soil.

3 MATERIALS AND METHODS

3.1 Site

Experiments were located at a property off Early Valley Road on the Port Hills of Christchurch (43°37'S, 172°34'E). The experimental site consists of two areas, 20 ha of burnt gorse and 20 ha of burnt pasture (Plate 3.1). The gorse area was completely burnt in the fire and the pasture area had varying intensities of burning. Soil samples were taken at a depth of 7.5 cm from the south facing side of the burnt gorse area and the burnt pasture area. The soil samples were analysed by Hill Laboratories. The results of these are summarised in Table 3.1. The soil test results indicate that the burnt pasture area has a low amount of available phosphorous and sulphur. The burnt gorse area has adequate levels of available phosphorous.

Plate 3.1 Aerial view of the site showing the two different areas; burnt gorse area and burnt pasture area prior to the fire.

Table 3.1 Summary of soil tests for the burnt pasture and burnt gorse areas on the 10/04/17 on the Port Hills, Canterbury**.**

Analysis	Burnt pasture	Burnt gorse	Recommended
pH	5.7	5.8	5.5-6.0
Potentially available N (kg/ha)	68	60	50-75
Olsen P (mg/L)	5	19	20
Potassium (me/100g)	0.60	0.45	0.3-0.6
Sulphate sulphur (mg/kg)	4	29	10-12

3.2 Climate data

Weather data was collected from Broadfields meteorological station. Monthly rainfall and mean air temperature for 2017 and a 30 year average (1981 – 2010) are presented in Figure 3.1 and Figure 3.2. The rainfall in February, when the fire started, was 38 mm lower than average. However, rainfall was higher than average in March by 24 mm and April and July by 70 mm. May and June also had a lower rainfall than average. The average monthly temperatures of 2017 were consistent with the 30 year average.

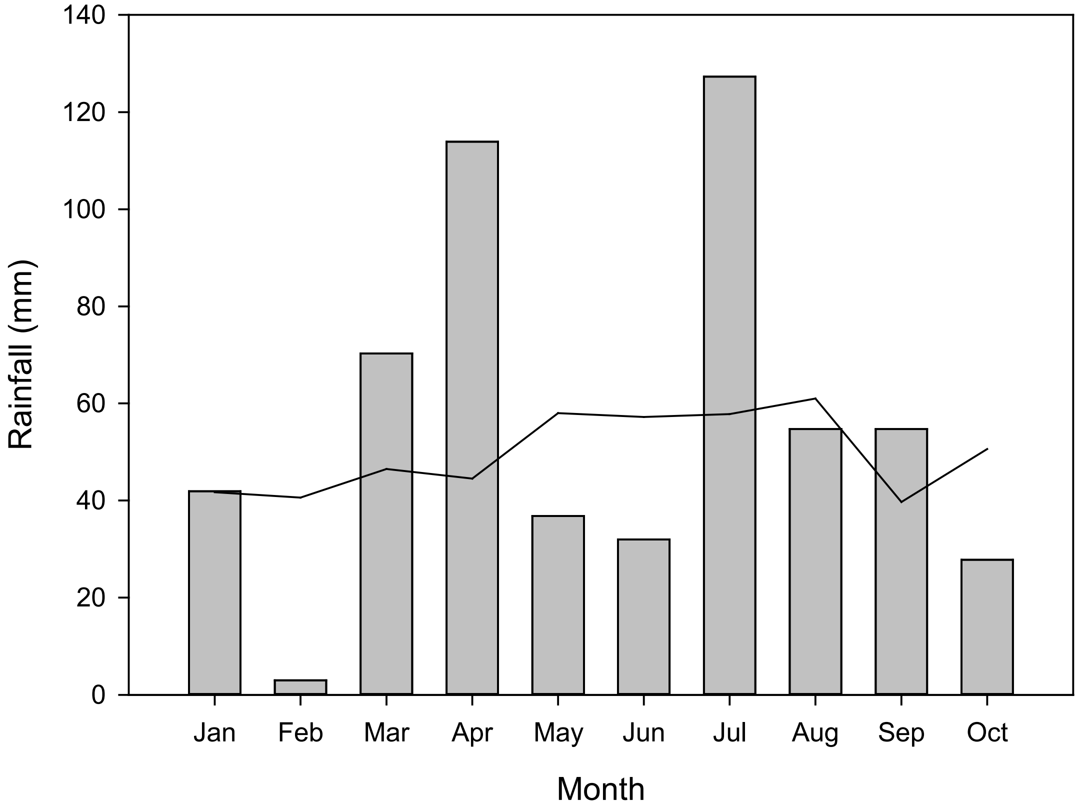

Figure 3.1 30 year average (1981 – 2010) (-) and 2017 monthly rainfall for Broadfields, Lincoln (NIWA, 2017).

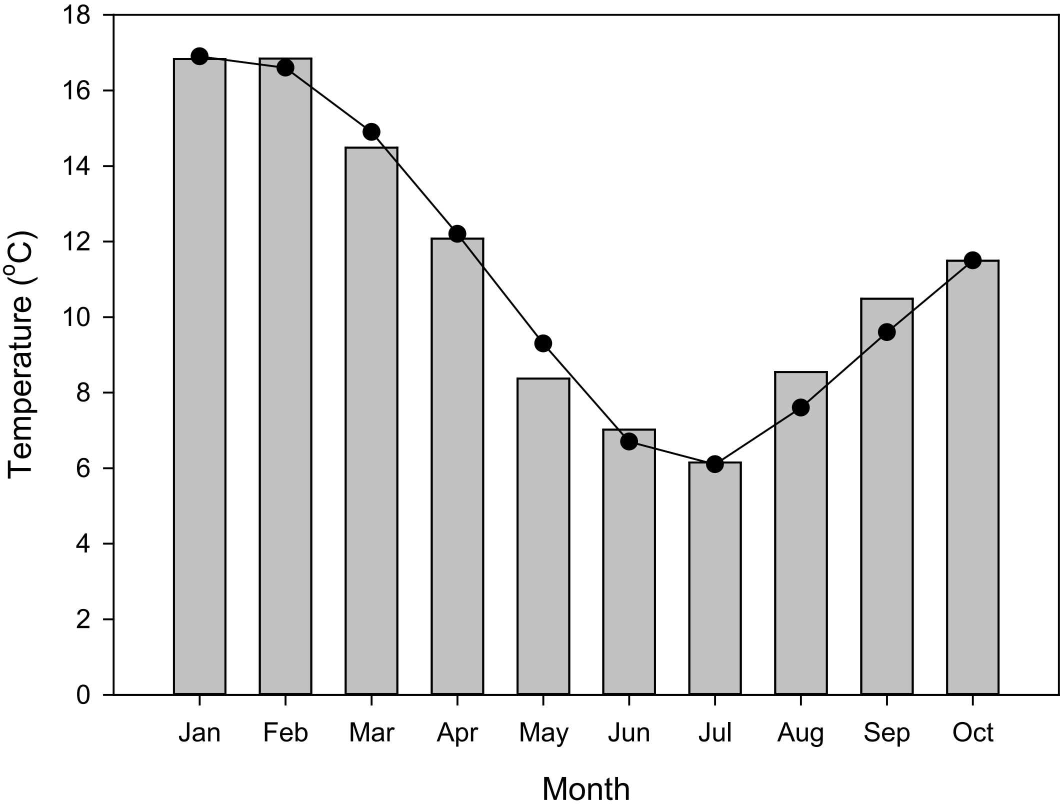

Figure 3.2 30 year average (1981 – 2010) (-) and 2017 mean air temperature for Broadfields, Lincoln (NIWA, 2017).

3.3 Experiment 1: Burnt pasture transects

In the burnt pasture area six 20 m transects were marked out. Two of these were in an area where pasture was completely burnt, two in an area that was partially burnt and two in an unburnt area. Every two weeks from the 26th March, a 0.01 m^2 quadrat was used to count subterranean clover seedlings every 20 m. As plants grew it became difficult to identify and count individual plants. Therefore, from the 26th May a visual score was used to determine the percentages of the four main components, grass, clover, dead material, weeds, within a round 0.1 m^2 quadrat. Six visual scores were taken from each of the transects. Weeds found in the burnt treatments were mostly yarrow (*Achillea millefolium*). Weeds found in the partially burnt and unburnt treatments were mostly hawkweeds (*Hieraceum*) and narrow leaved plantain (*Plantago lanceolata*).

Three herbage cuts from a $0.1m^2$ quadrat were taken from each transect on the 4th April and the 5th September to determine botanical composition. The samples were separated into grass, clover, dead material and weeds. The samples were then dried at 60ºC for 72 hours before being weighed.

3.4 Experiment 2: Burnt gorse plots

Eight paired plots (1.4 x 1.9 m) were marked out on the south facing hillside of the burnt gorse area. On the 17th March 2017, the area was oversown by a helicopter with 10 kg/ha Italian ryegrass, 5 kg/ha Nui perennial ryegrass, 5 kg/ha Woogenellup subterranean clover and 2 kg/ha cocksfoot. A sheet was pegged out over one of each pair of the plots to prevent seed from falling on these areas to create a seeded plot and an unseeded control (Plate 3.2).

Plate 3.2 Sheet pegged out over Plot 4 to prevent oversown seed landing on the plot on the 17/03/2017 on the Port Hills, Canterbury (Photo: Derrick Moot).

Gorse, subterranean clover and grass (Italian, perennial ryegrass and cocksfoot) seedlings within a fixed 0.01 m^2 quadrat were counted. Ten counts were taken from each plot with stakes placed in each plot to ensure the same areas were counted each time. Counts were taken every two weeks starting 28th March until May 26th. After this, counts were taken every 3-4 weeks depending on weather until 3rd October. The number of grass seedlings was determined by looking at the base of the plant to prevent tillers being counted as individual seedlings.

3.5 Experiment 3: North and south transects

In the burnt gorse area four 20 m transects were placed going down the hillside. Two transects were placed on the south slope with the other two placed on the north slope at a similar altitude (Plate 3.3). Gorse, subterranean clover and grass seedlings were counted within a 0.01 m^2 quadrat placed randomly along the transects every 1 m. Counts were taken at the same frequency as for Experiment 2.

Plate 3.3 Position of transects on north facing slope of the gorse gully on the Port Hills, Canterbury. Photo taken 21/04/17.

3.6 Experiment 4: Herbicides

Experiment 4 consisted of eight different herbicide treatments (Table 3.2). Three of these involved a herbicide mix with saflufenacil and another herbicide and the remaining five treatments were single herbicides. There were four replicates of each herbicide in a randomized block design (Appendix 6.1). Plots were 2 x 2 m. Before herbicides were applied, oversown grass that had established was trimmed to around 3 cm above soil height. This ensured that all gorse seedlings were wet with herbicide at spraying. Reps 1 and 2 were sprayed on the 21st August and Reps 3 and 4 on the 27th September. Spraying of Reps 3 and 4 was delayed due to windy and wet weather. The plots were sprayed using a handheld knapsack boom. Gorse seedlings were sprayed to the point of run off. The herbicides were sprayed on a calm day to minimise drift between plots.

Table 3.2 Eight herbicide treatments, active ingredients (a.i.) and rates used to spray gorse seedlings on the Port Hills, Canterbury**.**

Treatment	Active ingredient	Concentration of a.i.	Knapsack dilution (herbicide/L H_2O)
Tordon	Picloram + triclopyr + aminopyralid	100 + 300 + 8 g/L	6.0 ml
Escort	Metsulfuron-methyl	600 g/kg	0.5 g
Grazon	Triclopyr	600 g/l	6.0 ml
Terb 500	Terbuthylazine	500 g/l	55.0 ml
Roundup	Glyphosate	360 g/l	10.0 ml
Sharpen + Roundup	Saflufenacil + glyphosate	700 g/kg + 360 g/l	0.175 g + 10.0ml
Sharpen + Escort	Saflufenacil + metsulfuron-methyl	700 g/kg + 600 g/kg	0.175 g + 0.5 g
Sharpen + Grazon	Saflufenacil + triclopyr	700 g/kg + 600 g/l	0.175 g + 6.0 ml

Visual assessments were taken using the European Weed Research Society (EWRS) rating system shown in Table 3.3. A $0.1m^2$ quadrat was placed on a permanent marker in each plot and a score was given to gorse, grass and weeds within the quadrat. Visual assessments were taken as per Table 3.4. Chickweed (*Stellaria media*) was the most common weed found in the burnt gorse area.

Table 3.3: European Weed Research Society (EWRS) system used to assess herbicide damage of gorse, grass and weeds on the Port Hills, Canterbury.

Rating	Description of effects
1	Healthy plant
2	Very mild symptoms
3	Mild but clearly recognisable system
4	More severe symptoms but no effect on yield
5	Reduction in yield expected – plant is commercially unacceptable
6	Commercially unacceptable
7	Commercially unacceptable
8	Commercially unacceptable
9	Heavy damage to total kill

Table 3.4 Dates EWRS assessments were taken of herbicide effects on gorses, grass and weeds on the Port Hills, Canterbury. WAT = weeks after treatment.

WAT	Reps 1 + 2	Reps 3 + 4
1	28/08/17	03/10/17
2	05/09/17	-
4	21/09/17	-
5	-	30/10/17
6	03/10/17	-

3.7 Statistical analysis

Statistical analysis were preformed using GENSTAT 18. A one way ANOVA was used to detect any difference in subterranean clover seedlings, DM production and composition between burnt, partially burnt and unburnt pasture in Experiment 1. A two sample t-test was used to determine if there was a difference in gorse seedling number between seeded plots and unseeded control plots in Experiment 2. A two sample t-test also was used to determine if there was a difference in gorse, grass and clover seedling number between north and south facing slopes in Experiment 3. A one way ANOVA was used to if there was a difference in gorse and grass seedlings between the different herbicides in Experiment 4. Means were separated using Fisher's protected least significant difference (LSD) test. Unprotected LSDs were also used on occassion when the P value was not significant due to the heterogeneity of the data.

4 RESULTS

4.1 Experiment 1: Burnt pasture transects

4.1.1 Dry matter production

As expected, the burnt pasture had the lowest ($P<0.016$) dry matter yield of 526 kg DM/ha on the 4th April (Table 4.1). This was a third of the partially burnt pasture (1780 kg DM/ha) and a quarter of the unburnt pasture (1980 kg DM/ha). The burnt pasture had the highest increase of DM between the two harvest dates of 964 kg DM/ha. The unburnt pasture increased by 680 kg DM/ha and the DM of the partially burnt pasture was unchanged.

Table 4.1 Dry matter (kg DM/ha) of burnt, partially burnt and unburnt pasture at two harvest dates on the Port Hills, Canterbury.

Treatment	04/04/17	05/09/17
Burnt	526 $_b$	1490 $_b$
Partially burnt	1780 $_a$	1760 $_b$
Unburnt	1980 $_a$	2660 $_a$
P value	0.016	0.08
LSD (SEM)	1014 (194)	707 (135)

Note: Data within columns with a letter subscript in common are not significantly different at $P>0.05$. LSD is the least significant difference with the standard error of the mean (SEM) also given.

4.1.2 Pasture composition and cover

On the first measurement on the 28th March, there were ~650 plants/m^2 of subterranean clover seedlings on the burnt pasture areas compared with ($P<0.001$) the ~90 plants/m^2 on the partially burnt pasture and ~40 plants/m^2 on the unburnt pasture areas (Table 4.2). Thus, there were 610 plants/m^2 more on the burnt pasture compared with the unburnt pasture on the 28th March without any seed being sown. The number of clover seedlings on the burnt pasture had dropped to 375 plants/m^2 four weeks later but this number was still higher ($P<0.001$) than the partially burnt (92.5 plants/m^2) and unburnt pasture (27.5 plants/m^2).

Table 4.2 Subterranean clover seedlings (plants/m^2) on burnt, partially burnt and unburnt pastures on the Port Hills, Canterbury on two measurement dates.

Date	Burnt	Partially burnt	Unburnt
28/03/17	648 $_a$	88.0 $_b$	37.5 $_b$
P value	<0.001		
LSD (SEM)	133.9 (36.3)		
21/04/17	375 $_a$	92.5 $_b$	27.5 $_b$
P value	<0.001		
LSD (SEM)	84.10 (32.7)		

Note: Data across rows with a letter subscript in common are not significantly different at P>0.05. LSD is the least significant difference with the standard error of the mean (SEM) also given.

Counting individual seedlings was impossible by the end of March so quadrat cuts were taken for assessment of botanical composition. The burnt pasture had the highest (P<0.05) amount of grass (64.4%) and clover (4.75%) compared with the other pasture areas on the 4th April (Table 4.3). The burnt pasture also had the lowest proportion of dead material (P<0.001). These results highlight that the partially burnt and unburnt pastures were almost 50% dead material. There was no difference between the treatments in terms of other pasture components.

Table 4.3 Botanical composition (%) of burnt, partially burnt and unburnt pastures on the Port Hills, Canterbury on the 04/04/17.

Treatment	Grass	Clover	Dead	Weeds
Burnt	64.4 $_a$	4.75 $_a$	18.0 $_b$	12.8
Partially	45.7 $_b$	1.63 $_b$	47.7 $_a$	5.00
Unburnt	38.2 $_b$	2.82 $_{ab}$	46.1 $_a$	12.9
P value	0.008	0.044	<0.001	0.341
LSD (SEM)	15.60 (5.17)	2.417 (0.80)	12.10 (4.01)	12.74 (4.22)

Note: Data within columns with a letter subscript in common are not significantly different at P>0.05. LSD is the least significant difference with the standard error of the mean (SEM) also given.

The burnt pasture had a lower (P<0.001) proportion of grass and a higher (P<0.001) proportion of clover compared with the partially burnt and unburnt pastures when visually assessed on the 27th June and 16th August (Table 4.4 and Table 4.5). The unburnt pasture had the highest amount of dead material with none detected in the burnt and partially burnt areas. This was because the material was found at the base of the plant and was not visible when doing a visual assessment of cover. There was no difference in the proportion of weeds between the pastures. The composition of the pastures did not change between the two sampling dates. However, the clover content increased from 44% to 49% in the burnt pasture and decreased from 13.8% to 7.5% in the unburnt pasture.

Table 4.4 Visual assessment of cover (%) of burnt, partially burnt and unburnt pastures on the Port Hills, Canterbury on the 27/06/17.

Treatment	Grass	Clover	Dead	Weeds
Burnt	50.0 $_b$	44.2 $_a$	0.00 $_b$	5.83
Partially burnt	69.2 $_a$	22.9 $_b$	0.00 $_b$	7.92
Unburnt	77.5 $_a$	13.8 $_b$	5.42 $_a$	3.33
P value	<0.001	<0.001	<0.001	0.110
LSD	12.24 (4.94)	12.99 (5.11)	2.792 (0.85)	4.292 (1.38)

Note: Data within columns with a letter subscript in common are not significantly different at P>0.05. LSD is the least significant difference with the standard error of the mean (SEM) also given.

Table 4.5 Visual assessment of cover (%) of burnt, partially burnt and unburnt pastures on the Port Hills, Canterbury on the 16/08/17.

Treatment	Grass	Clover	Dead	Weeds
Burnt	48.3 $_b$	49.2 $_a$	0 $_b$	2.50
Partially burnt	78.3 $_a$	17.5 $_b$	0 $_b$	4.58
Unburnt	78.8 $_a$	7.5 $_b$	9.2 $_a$	4.58
P value	<0.001	<0.001	0.001	0.483
LSD	15.29 (4.25)	15.05 (4.51)	5.30 (0.97)	4.014 (1.49)

Note: Data within columns with a letter subscript in common are not significantly different at P>0.05. LSD is the least significant difference with the standard error of the mean (SEM) also given.

There was no difference in the proportion of grass (P<0.124) and weeds (P<0.518) between the three pasture areas on the 5th September (Table 4.6). Clover was highest (P<0.017) in the burnt pasture, making up 26.5% of the total DM compared with <8% in the unburnt areas. Dead material was highest (P<0.003) at 30.1% in the unburnt pasture.

Table 4.6 Botanical composition (%) of burnt, partially burnt and unburnt pastures on the Port Hills, Canterbury on the 05/09/17.

Treatment	Grass	Clover	Dead	Weeds
Burnt	62.5	26.5 $_a$	6.90 $_b$	4.11
Partially	77.0	7.71 $_b$	9.35 $_b$	5.94
Unburnt	62.5	4.00 $_b$	30.1 $_a$	3.40
P value	0.124	0.017	0.003	0.518
LSD (SEM)	16.27 (5.39)	15.59 (5.17)	13.18 (4.37)	4.762 (1.58)

Note: Data within columns with a letter subscript in common are not significantly different at P>0.05. LSD is the least significant difference with the standard error of the mean (SEM) also given.

4.2 Experiment 2: Burnt gorse plots

In both treatments, there were ~100 gorse seedlings/m^2 in April (Figure 4.1). The number of gorse seedlings increased, reaching their highest population of 680 plants/m^2 on the 26th May. The number of gorse seedlings then began to decline in late June. On the 3rd October there was an indication of fewer ($P<0.053$) gorse seedlings in the seeded plots (447 plants/m^2) compared with the unseeded control (610 plants/m^2). One of the plots, Plot 4, appeared to have been missed when oversowing and had very few grass seedlings within it (Plate 4.1) compared with the other plots (Plate 4.2). When data from this plot was removed the difference between the seeded and unseeded plots on the 3rd October was evident. There were 52% fewer gorse seedlings in the seeded plots compared with the unseeded plots ($P<0.001$). There was no difference between the sown and unsown plots at any other times when Plot 4 was removed from the analysis.

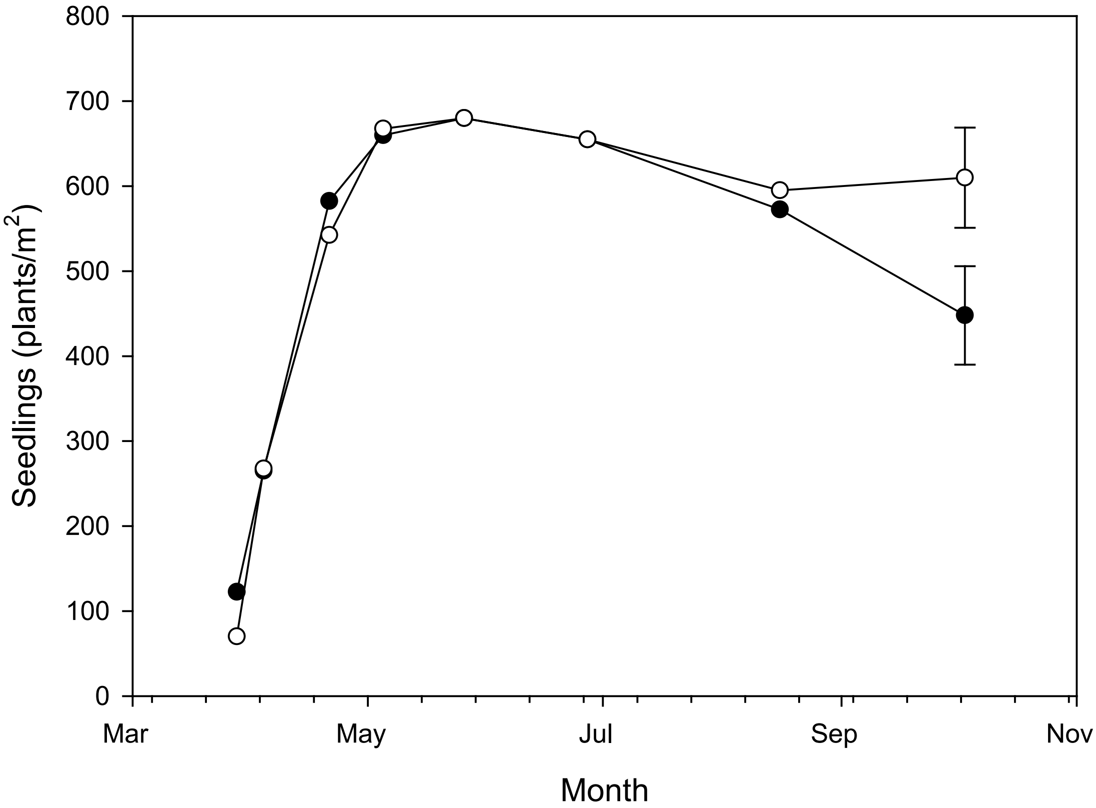

Figure 4.1 Gorse seedlings (plants/m^2) in plots oversown with (●) or without (○) pasture seed on the Port Hills, Canterbury overtime. Error bars represent the standard error of the mean.

Plate 4.1 Plot 4 that had been missed while oversowing, on the 27/06/2017.

Plate 4.2 Establishment of oversown Italian ryegrass on Plot 2 on the 27/06/2017. Left – unseeded treatment, right – seeded treatment.

4.3 Experiment 3: North and south transects

4.3.1 Gorse seedlings

The initial count on the 28th March showed there was no difference between the number of gorse seedlings on the south and north facing slopes (Figure 4.2). The number of gorse seedlings increased from initial counts for both slopes but the increase was faster on the south slope. Three weeks later there were more ($P<0.001$) gorse seedlings on the south slope (408 plants/m^2) compared with the north slope (125 plants/m^2). This trend continued throughout the winter. Gorse seedlings reached their highest population for both slopes on the 27th June. At this time there were more ($P<0.001$) gorse seedlings on the south slope (730 plants/m^2) than the north slope (210 seedlings/m^2). After this, gorse seedlings began to decline on both slopes, but this was more rapid on the south slope. On the last measurement date, 3rd October, there were 35% more ($P<0.002$) gorse seedlings on the south side compared with the north side.

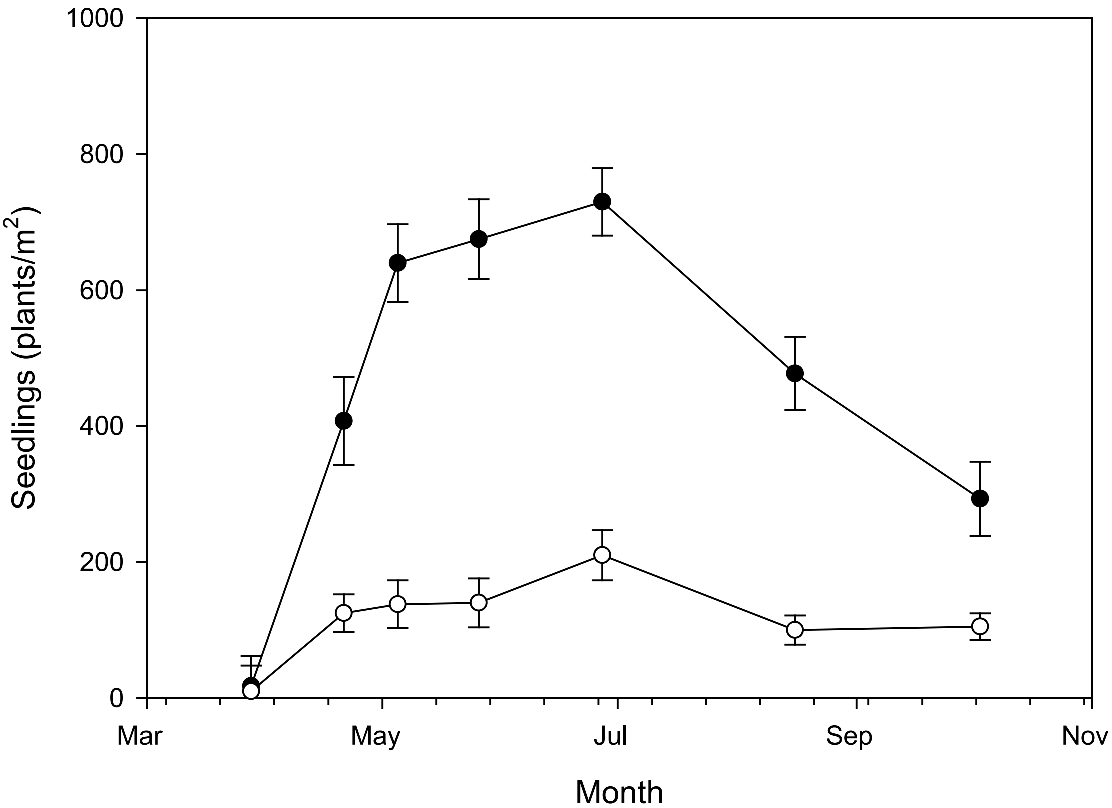

Figure 4.2 Gorse seedlings (plants/m^2) on north (○) and south (●) facing slopes after burning on the Port Hills, Canterbury over time. Error bars represent the standard error of the mean.

4.3.2 Italian ryegrass seedlings

Five weeks after oversowing, there were 340 Italian ryegrass seedlings/m^2 emerged on the south slope compared with (P<0.001) 75 plants/m^2 on the north slope (Figure 4.3) From this point the number of grass seedlings on the south slope declined to ~200 plants/m^2 in June which was still ~150 plants/m^2 more (P<0.001) than the north slope. These ryegrass populations were not different to those on the final measurement date with the 143 plants/m^2 on the south slope still higher (P<0.001) than the 35 plants/m^2 on the north slope.

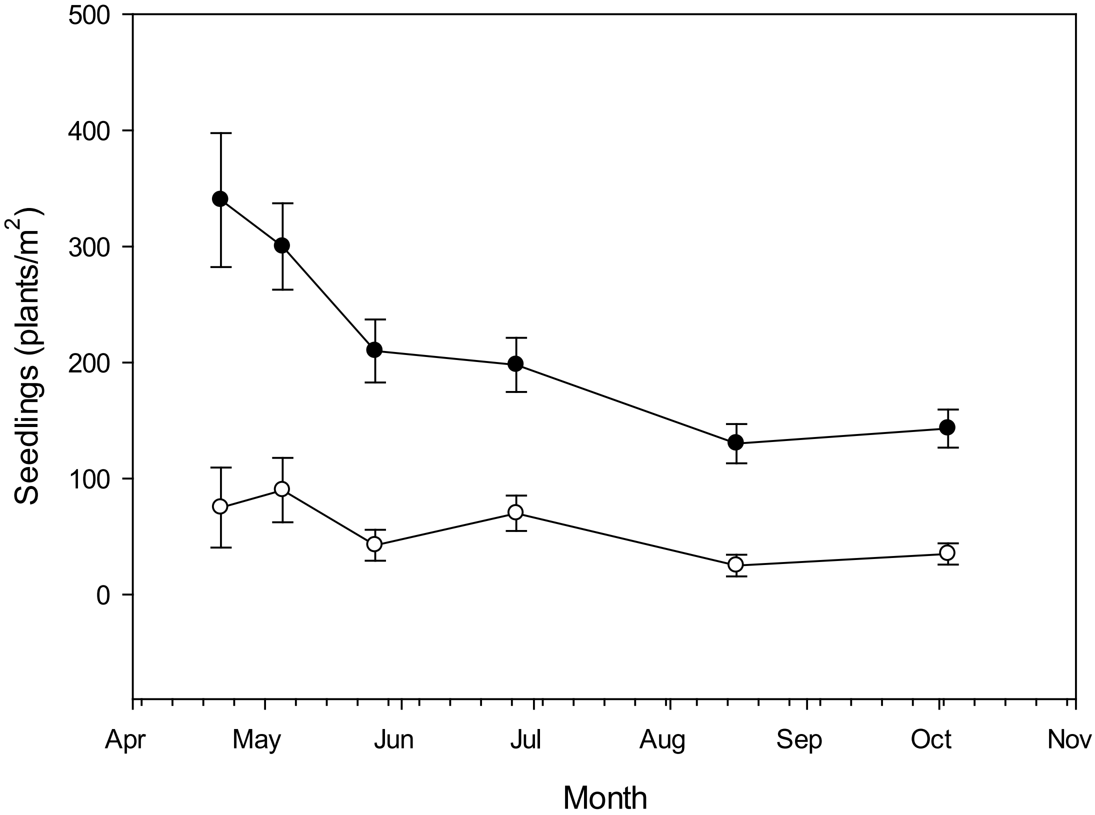

Figure 4.3 Italian ryegrass seedlings (plants/m^2) on north (○) and south (●) facing slopes after burning on the Port Hills, Canterbury. Error bars represent the standard error of the mean.

4.3.3 Subterranean clover seedlings

The temporal pattern of establishment for subterranean clover was consistent with the grass but populations were reversed (Figure 4.4). Specifically, there were more subterranean clover seedlings on the north slope compared with the south slope across the measurement period. At the first measurement there were ~100 subterranean clover seedlings/m^2 but fewer

(P<0.012) than 20 plants/m^2 on the north slope. The number declined to 45 plants/m^2 on the north slope but this was still more (P<0.001) than the consistent 5-15 plants/m^2 found on the south slope on each measurement date.

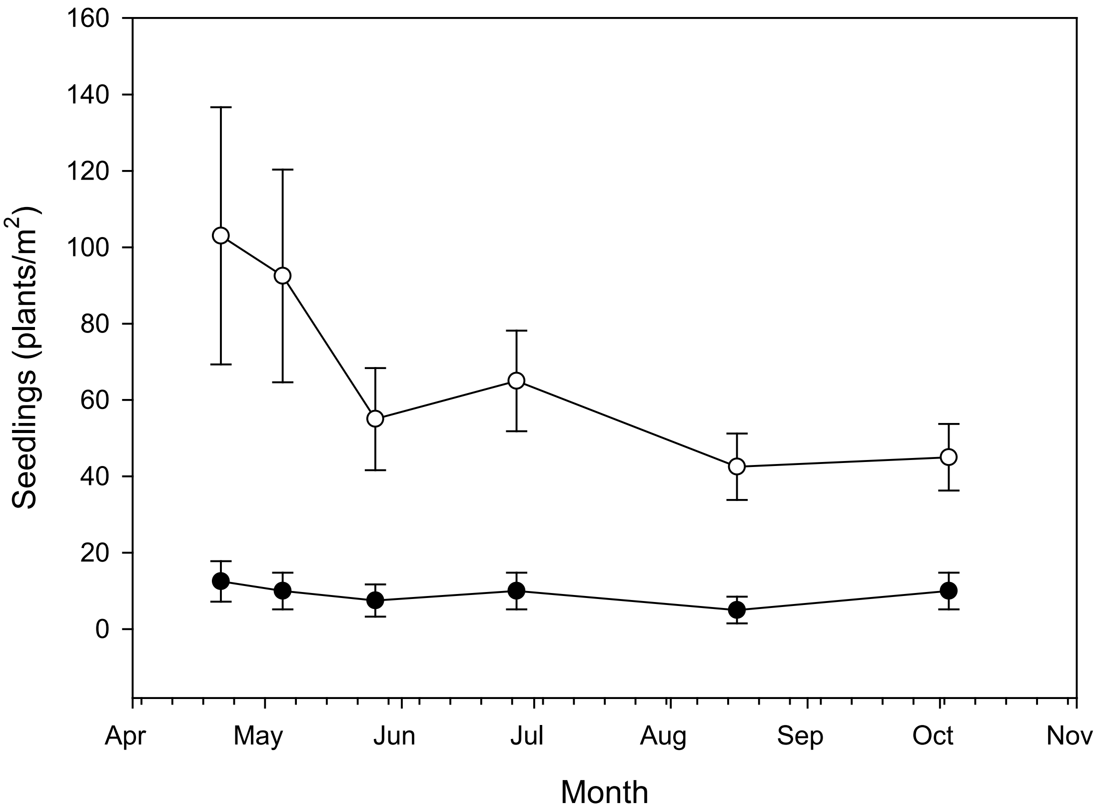

Figure 4.4 Subterranean clover seedlings (plants/m^2) on north (○) and south (●) facing slopes after burning in the Port Hills, Canterbury over time. Error bars represent the standard error of the mean.

4.4 Experiment 4: Herbicides

4.4.1 August application

The EWRS ratings of the different herbicide treatments on gorse seedlings following the August application are shown in Table 4.7. One week after treatment only the combination saflufenacil treatments had any effect on the gorse seedlings, with the saflufenacil + glyphosate treatment having the highest rating of 2.5 (P<0.015). This was still a low effect but indicated an earlier response than the glyphosate alone. Two weeks after treatment saflufenacil + glyphosate had the highest (P<0.002) rating of 7 compared with the rest of the treatments. Two weeks after treatment there was some effect seen in the single herbicide treatments, except for terbuthylazine and metsulfuron-methyl which were still showing no effect (EWRS = 1). At four weeks after application the saflufenacil + glyphosate treatment still had the highest ($P<0.002$) rating of 7. Terbuthylazine still showed no effect on the gorse seedlings at four weeks after treatment. At this stage of the experiment some of the single herbicide treatments were beginning to show equivalent EWRS scores to some of the saflufenacil treatments. For example, picloram and glyphosate both caused more damage than saflufenacil + metsulfuron-methyl.

At the end of monitoring after six weeks, all treatments, excluding metsulfuron-methyl and terbuthylazine, had all visually affected the gorse seedlings. Glyphosate produced the highest damage to the gorse seedlings with a rating of 8 ($P<0.001$). However, none of the treatments had killed the gorse seedlings within six weeks and there was still green material present on all seedlings in all the treatments.

Table 4.7 Gorse seedling damage visually assessed using the EWRS system after application of 8 herbicide treatments on the 12/09/17 on the Port Hills, Canterbury. WAT – weeks after treatment.

Herbicide	1 WAT	2 WAT	4 WAT	6 WAT
Picloram, triclopyr, aminopyralid	1 $_{c}$	3.0 $_{b}$	4.5 $_{cd}$	6.5 $_{ab}$
Metsulfuron-methyl	1 $_{c}$	1.0 $_{c}$	3.0 $_{d}$	4.0 $_{c}$
Triclopyr	1 $_{c}$	2.0 $_{c}$	4.5 $_{cd}$	5.5 $_{bc}$
Terbuthylazine	1 $_{c}$	1.0 $_{c}$	1.0 $_{e}$	1.5 $_{d}$
Glyphosate	1 $_{c}$	1.5 $_{c}$	5.0 $_{bc}$	7.5 $_{a}$
S + glyphosate	2.5 $_{a}$	7.0 $_{a}$	7.0 $_{a}$	7.0 $_{ab}$
S + metsulfuron-methyl	1.5 $_{bc}$	3.0 $_{bc}$	4.5 $_{cd}$	6.0 $_{ab}$
S + triclopyr	2 $_{ab}$	5.5 $_{ab}$	6.5 $_{ab}$	7.0 $_{ab}$
P value	0.015	0.002	0.002	<0.001
LSD (SEM)	0.815 (0.25)	2.157 (0.66)	1.997 (0.61)	1.631 (0.50)

Note: 1 = healthy plant, 9 = total kill, S = saflufenacil. Data within columns with a letter subscript in common are not significantly different at $P>0.05$. LSD is the least significant difference with the standard error of the mean (SEM) also given.

One week after spraying only the saflufenacil + glyphosate and picloram treatments were showing mild effects on the grass (EWRS < 3) with the rest of the treatments showing no effect (Table 4.8). Saflufenacil treatments mixed with triclopyr and glyphosate produced the highest ratings ($P<0.001$) above 5.0 after two weeks, making the damage to grass plants commercially unacceptable. The remaining treatments had mild or no effects on grass after two weeks. Four weeks after spraying both saflufenacil + glyphosate and saflufenacil +

triclopyr treatments had lower damage ratings than two weeks before suggesting that the effects of the herbicide were starting to wear off and the grass was recovering.

At the end of the six weeks, three treatments (glyphosate, saflufenacil + glyphosate, saflufenacil + metsulfuron-methyl) had damaged the grass to a commercially unacceptable level (EWRS < 5). As with the gorse seedlings, none of the treatments killed the grass over the six weeks with glyphosate having damaged the grass the most (P<0.024) with a rating of 8. All other treatments (picloram, saflufenacil + triclopyr, triclopyr, terbuthylazine) had no significant effect on grass.

Table 4.8 Grass seedling damage visually assessed using the EWRS system after application of 8 herbicide treatments on the 12/09/17 on the Port Hills, Canterbury. WAT – weeks after treatment.

Herbicide	1 WAT	2 WAT	4 WAT	6 WAT
Picloram, triclopyr, aminopyralid	1.5 $_{ab}$	1.0 $_{b}$	1.0 $_{b}$	1.5 $_{b}$
Metsulfuron-methyl	1.0 $_{b}$	1.0 $_{b}$	3.0 $_{ab}$	4.0 $_{a}$
Triclopyr	1.0 $_{b}$	2.5 $_{b}$	1.5 $_{b}$	1.0 $_{b}$
Terbuthylazine	1.0 $_{b}$	1.0 $_{b}$	1.0 $_{b}$	1.0 $_{b}$
Glyphosate	1.0 $_{b}$	1.0 $_{b}$	4.5 $_{a}$	8.0 $_{a}$
S + glyphosate	2.0 $_{a}$	7.0 $_{a}$	5.0 $_{a}$	6.0 $_{a}$
S + metsulfuron-methyl	1.0 $_{b}$	2.5 $_{b}$	4.0 $_{a}$	6.0 $_{a}$
S + triclopyr	1.0 $_{b}$	5.5 $_{a}$	4.5 $_{a}$	1.0 $_{b}$
P value	0.024	<0.001	0.037	0.024
LSD (SEM)	0.8153 (0.25)	1.525 (0.47)	2.765 (0.61)	4.197 (1.29)

Note: 1 = healthy plant, 9 = total kill, S = saflufenacil. Data within columns with a letter subscript in common are not significantly different at P>0.05. LSD is the least significant difference with the standard error of the mean (SEM) also given.

There was an indication (P<0.055) of differences among the eight herbicide treatments for their effect on broadleaf weeds after one week (Table 4.9). Specifically, treatments that included saflufenacil had EWRS scores of 2-2.5 compared with 1.0 for the herbicides alone. These differences became more obvious (P<0.002) after two weeks when the saflufenacil + triclopyr and saflufenacil + glyphosate treatments both had a rating of 7.5. All treatments, excluding terbuthylazine, had a rating 5 or higher after four weeks, meaning that the yield of the weeds had been decreased. Saflufenacil treatments did result in more broadleaf weed damage in the first four weeks than the single herbicide treatments as with the gorse seedlings. At the end of the six weeks saflufenacil + triclopyr and picloram had both killed the broadleaf weeds with a rating of 9 (P<0.001). All other treatments had a rating 7.5 or higher except terbuthylazine which still had a rating of 4.0.

Table 4.9 Weed damage visually assessed using the EWRS system after application of 8 herbicide treatments on the 12/09/17 on the Port Hills, Canterbury. WAT – weeks after treatment.

Herbicide	1 WAT	2 WAT	4 WAT	6 WAT
Picloram, triclopyr, aminopyralid	1.5	4.0 $_{b}$	7.5 $_{ab}$	9.0 $_{a}$
Metsulfuron-methyl	1.0	1.5 $_{b}$	6.5 $_{c}$	7.5 $_{b}$
Triclopyr	1.0	3.5 $_{bc}$	6.5 $_{c}$	7.5 $_{b}$
Terbuthylazine	1.0	1.0 $_{c}$	1.0 $_{e}$	4.0 $_{c}$
Glyphosate	1.0	6.0 $_{ab}$	7.0 $_{bc}$	8.5 $_{ab}$
S + glyphosate	2.5	7.5 $_{a}$	8.0 $_{a}$	8.0 $_{ab}$
S + metsulfuron-methyl	1.5	2.5 $_{bc}$	5.0 $_{d}$	7.5 $_{b}$
S + triclopyr	2.0	7.5 $_{a}$	8.0 $_{a}$	9.0 $_{a}$
P value	0.055	0.002	<0.001	<0.001
LSD (SEM)	0.999 (0.31)	2.642 (0.81)	0.999 (0.32)	1.153 (0.25)

Note: 1 = healthy plant, 9 = total kill, S = saflufenacil. Data within columns with a letter subscript in common are not significantly different at P>0.05. LSD is the least significant difference with the standard error of the mean (SEM) also given.

4.4.2 September application

The EWRS ratings of the different herbicides on gorse seedlings are shown in Table 4.10. One week after spraying the saflufenacil treatments had the highest (P<0.001) EWRS ratings of 4.5 or higher. Four weeks after treatment glyphosate, saflufenacil + glyphosate and terbuthylazine had caused the most (P<0.033) damage to the gorse seedling with an EWRS rating of >8.0. Metsulfuron-methyl had the lowest rating of 6.5.

All of the herbicides had a higher EWRS rating for gorse seedlings four weeks after application in September compared with six weeks after application in August (Table 4.7). Terbuthylazine showed the greatest increase from 1.5 six weeks after application in August, to 8.5 four weeks after application in September.

Table 4.10 Gorse seedling damage visually assessed using the EWRS system after application of 8 herbicide treatments on the 12/09/17 on the Port Hills of Canterbury. WAT – weeks after treatment**.**

Herbicide	1 WAT	4 WAT
Picloram, triclopyr, aminopyralid	3.5 $_{bc}$	7.5 $_{bcd}$
Metsulfuron-methyl	1.5 $_{d}$	6.5 $_{d}$
Triclopyr	3.0 $_{cd}$	7.0 $_{cd}$
Terbuthylazine	2.0 $_{cd}$	8.5 $_{ab}$
Glyphosate	1.0 $_{d}$	9.0 $_{a}$
S + glyphosate	5.5 $_{a}$	8.0 $_{abc}$
S + metsulfuron-methyl	4.5 $_{abc}$	7.5 $_{bcd}$
S + triclopyr	5.0 $_{ab}$	7.5 $_{bcd}$
P value	0.001	0.033
LSD (SEM)	1.631 (0.50)	1.289 (0.39)

Note: 1 = healthy plant, 9 = total kill, S = saflufenacil. Data within columns with a letter subscript in common are not significantly different at P>0.05. LSD is the least significant difference with the standard error of the mean (SEM) also given.

The EWRS ratings of different herbicides applied in September on grass seedlings are shown in Table 4.11. One week after treatment there was no difference (P<0.306) in the visual damage caused by the herbicides with all herbicides having an EWRS rating of <4.5. Four weeks after application glyphosate had the greatest damage on the gorse seedlings with a score of 8.0. Picloram and triclopyr both showed little or no damage to the grass seedlings with EWRS scores of 1.5 and 1.0, respectively.

Table 4.11 Grass seedling damage visually assessed using the EWRS system after application of 8 herbicide treatments on the 12/09/17 on the Port Hills, Canterbury. WAT – weeks after treatment.

Herbicide	1 WAT	4 WAT
Picloram, triclopyr, aminopyralid	1.0	1.5 $_{bc}$
Metsulfuron-methyl	2.0	5.5 $_{abc}$
Triclopyr	1.5	1.0 $_{c}$
Terbuthylazine	1.5	6.5 $_{ab}$
Glyphosate	2.0	8.5 $_{a}$
S + glyphosate	4.0	5.5 $_{abc}$
S + metsulfuron-methyl	3.5	4.0 $_{abc}$
S + triclopyr	3.5	3.0 $_{bc}$
P value	0.306	0.104
LSD (SEM)	3.051 (0.94)	5.189 (1.59)

Note: 1 = healthy plant, 9 = total kill, S = saflufenacil. Data within columns with a letter subscript in common are not significantly different at P>0.05. LSD is the least significant difference with the standard error of the mean (SEM) also given.

Four weeks after treatment there was no difference (P<0.612) between the EWRS rating of the different herbicides on broadleaf weeds (Table 4.12). All herbicides had a rating of 8.0 or higher.

Table 4.12 Weed damage visually assessed using the EWRS system after application of 8 herbicide treatments on the 12/09/17 on the Port Hills, Canterbury. WAT – weeks after treatment.

Herbicide	1 WAT	4 WAT
Picloram, triclopyr, aminopyralid	5.0 $_{ab}$	8.0
Metsulfuron-methyl	2.5 $_{b}$	8.5
Triclopyr	5.0 $_{ab}$	8.5
Terbuthylazine	2.5 $_{b}$	9.0
Glyphosate	3.0 $_{b}$	8.5
S + glyphosate	5.0 $_{ab}$	8.0
S + metsulfuron-methyl	6.5 $_{a}$	9.0
S + triclopyr	4.5 $_{ab}$	8.0
P value	0.205	0.612
LSD (SEM)	3.459 (1.06)	1.525 (0.47)

Note: 1 = healthy plant, 9 = total kill, S = saflufenacil. Data within columns with a letter subscript in common are not significantly different at P>0.05. LSD is the least significant difference with the standard error of the mean (SEM) also given.

5 DISCUSSION

5.1 Experiment 1: Burnt pasture transects

5.1.1 Dry matter production

The burnt pasture showed the greatest increase in dry matter between April and September with a growth rate of 6.3 kg DM/ha/d (Table 4.1). The unburnt pasture also showed an increase in dry matter with a growth rate of 4.4 kg DM/ha/d. The partially burnt pasture showed no change in pasture production between April and September which was unexpected. This could be due to large variation in dry matter from the samples taken from the partially burnt transects. There is no literature regarding hill country pasture regeneration after fire but it is likely the effects are the same as defoliation. Hill country pastures are often hard grazed in autumn to remove dead material that built up over the summer. Pasture that had a stocking rate of 26 ewes/ha over autumn produced 2.0 t DM/ha over winter compared with a pasture with a lower stocking rate of 16 ewes/ha that only produced 1.2 t DM/ha (Jagusch *et al.,* 1978). Defoliation results in higher numbers of tillers and denser pastures and therefore more pasture production. The removal of dead material also allows more light to be intercepted by the pasture (Brougham, 1956). The fire in February removed all material in the burnt areas which would have lead to greater tillering and light interception of the pasture compared with unburnt pasture.

5.1.2 Pasture composition

Six weeks following the fire, a large number (648 plants/m^2) of subterranean clover seedlings had emerged on the burnt pasture area. This was significantly more subterranean clover seedlings than had emerged on the partially burnt and unburnt pasture (Table 4.2). This suggests the heat from the fire broke the hard coat of the subterranean clover seed. Legume seed has a hard testa that physically restricts water uptake, making the seed dormant (Morrison *et al.*, 1998). Dormancy is broken when the testa cracks, usually at the strophiole region which is the weakest part and also where water entry occurs. Fluctuations in temperatures between 60°C and 25°C have been shown to reduce the hardseed levels of subterranean clover (Lodge *et al.*, 1990). This is due to the expansion of the testa in high temperatures, followed by the contraction in cooler temperatures which weakens the testa. This allows water to be imbibed by the seed. The soil temperature during the fire could be as high as 60°C (Auld and Bradstock, 1996) making it hot enough to break the dormancy of the subterranean clover seed. However in the experiment by Lodge *et al.* (1990) repeated temperature fluctuations were over 11 months, which is much longer than what would occur following a fire. No research has been conducted on subterranean clover germination following a fire but Auld and O'connell (1991) found that seed dormancy of 35 Australian Fabaceae species was broken by soil temperatures that would occur in low (40°C in the top 2 cm of soil) and medium (>60°C in the top 2 cm of soil) intensity fire. A medium intensity fire would promote more germination than a low intensity fire. This explains why there was a greater germination in the burnt pastures compared with the partially burnt pasture. The soil temperatures in the partially burnt area would have been lower during the fire as the intensity was not as great. The higher than average rainfall in March and April (Figure 3.1) would have created ideal conditions for subterranean clover germination.

The amount of clover in the burnt pasture increased from 4.75% on the 04/04/17 to 26.5% on the 05/09/17 (Table 4.3 and 4.6). The clover content of the partially burnt and unburnt pasture only increased slightly. Visual assessments of cover also showed an increase in clover in the burnt pasture and decreases in clover in the partially burnt and unburnt pastures between two assessment dates (Table 4.4 and 4.5). The heat from the fire affected the germination of the seed but emergence and growth of the subterranean clover was affected by competition with the grass species. Dear *et al.* (1998) found the growth of emerging subterranean clover seedlings in pasture was higher when the grass was defoliated. This is due to reduced shading from grass once it has been defoliated allowing the clover seedling to intercept more light. The burnt pasture area was burnt to the ground, which allowed the emerging subterranean clover seedlings to intercept more light than those in the partially burnt and unburnt pastures where the grass was taller.

Clover seedlings in treatments where the grass had not been defoliated also had smaller roots compared with unshaded clover seedlings (Dear *et al.*, 1998). This would mean the clover seedlings in the partially burnt and unburnt pasture would not be able to access as much water as the clover seedlings in the burnt pasture. The amount of subterranean clover declined the unburnt pastures throughout the experiment. This is due to the higher amount of grass in these treatments also means the clover seedlings had more competition for water and nutrients than the clover seedlings in the burnt pasture. The Olsen P for the site was 5 (Table 3.1). Subterranean clover growth is reduced in phosphorous deficient soils (Gillingham *et al.*, 1998). This could also reduce the subterranean clovers ability to compete with the resident grasses. For subterranean clover to persist at this site phosphorous fertilizer would need to be applied.

The unburnt pasture had a higher proportion of dead material compared with the burnt and partially burnt pastures (Table 4.6). This was expected as dead material was removed in the fire. When visual assessments of cover were taken no dead material was found in the burnt and partially burnt pastures (Table 4.4 and 4.5). This is because the dead material in these pastures was at the base of the plant and only identified when cuts were taken for the botanical composition. The unburnt pastures contained dead seedheads that were visible when visually assessing cover.

5.2 Experiment 2: Burnt gorse plots

The objective of this experiment was to determine if grass could outcompete gorse seedlings. The majority of grass that established was Italian ryegrass due to having a shorter thermal time requirement for germination and emergence than cocksfoot (Moot *et al.*, 2000). Cocksfoot would have been slow to establish and was likely outcompeted by the Italian ryegrass. There was no difference in the number of gorse seedlings between the seeded and unseeded plots until six months after oversowing. At that point the seeded plots had 160 plants/m^2 fewer gorse seedlings than the unseeded plots (Figure 4.1). Gorse seedling populations decreased in both treatments in late August. This decrease in the unseeded plots was most likely due to competition between the gorse seedlings as the population was extreme (680 plants/m^2). The gorse population in the unseeded plots did not change (~600 plants/m^2) between the August and October measurements. However, the gorse seedling population in the seeded plots continued to decrease due to Italian ryegrass competition. Ivens and Mlowe (1980) found gorse growth decreased when grown together with perennial ryegrass compared with when it was grown in a monoculture. Italian ryegrass established quickly, with ~300 plants/m^2 initially establishing on the north facing slope (Figure 4.3). Italian ryegrass has a low thermal time requirement for 50% emergence (145°Cd) and a fast growth rate (Moot *et al.,* 2000). This meant the Italian ryegrass quickly grew taller than the gorse seedlings. This reduced the amount of light absorbed by the gorse seedlings and therefore the amount of photosynthesis and energy.

Nodulation of gorse roots was not measured in this experiment. However, Ivens and Mlowe (1980) found the root nodules/gorse plant declined by 70% when grown with perennial ryegrass compared with a gorse monoculture. This would decrease the amount of biological nitrogen fixation from the gorse which may result in less growth. However, a soil test of the site in early April showed high levels of potentially available N (Table 3.1), as the site has been covered in gorse for many years. It seems unlikely that nitrogen would be limiting gorse growth and that shading is a more likely reason for the decrease in gorse in seeded plots.

Gorse seedlings have a shorter and less extensive root system compared with ryegrass seedlings (Ivens and Mlowe, 1980). This gives them a disadvantage when competing with ryegrass for water and nutrients. This is another factor that could have affected gorse seedling population in the seeded plots. As the soil dries out over summer the grass will have an advantage over the gorse seedlings which may become water stressed and die.

The population of gorse seedlings in this experiment is high compared with other literature. Eight months after a gorse bush thicket was cleared in February, Ivens (1978) reported there were ~270 gorse seedlings/m^2 that had germinated. This compared with 610 gorse seedlings/m^2 in the unseeded plots in this experiment after a similar timeframe. The higher population of gorse seedlings in this experiment could be due to the fire breaking the dormancy and quickening the germination of the seeds (Zabkiewicz and Gaskin, 1978). The number of gorse seedlings was still high (447 plants/m^2) but it appears that Italian ryegrass competition has killed some of the gorse seedlings. This contrasts with Ivens and Mlowe (1980) and Davies *et al*. (2005) that found that perennial ryegrass competition alone did not result in the death of any gorse seedlings, only a reduction in dry weight. These experiments were only conducted for six and four months, respectively. As differences between gorse populations were not seen until 6.5 months after oversowing, it is possible that ryegrass competition may have resulted in the death of seedlings in the other experiments had they been continued for longer.

The oversowing in this experiment was inconsistent, with some areas being missed (Plate 4.1). This resulted in bare areas of ground where Italian ryegrass competition was not controlling the gorse seedlings. These areas would either have to be resown or sprayed with herbicides to eliminate the gorse seedlings.

5.3 Experiment 3: North and south transects

Higher populations of Italian ryegrass seedlings were found on the south facing slope of the gully compared with the north slope (Figure 4.3). Similar results were found by White *et al.* (1972) who showed that oversown perennial ryegrass had better establishment six months after sowing on the south slope (21.3 plants/m^2) compared with the north slope (4.7 plants/m^2). This was due to south slopes having a higher soil moisture (Radcliffe, 1982) allowing greater establishment of the ryegrass.

Subterranean clover established in higher numbers on the north facing slopes (Figure 4.4). This was expected as Power (2007) found higher levels of subterranean clover on north slope compared with south slopes. On the south slope where there is better establishment of Italian ryegrass, the subterranean clover is quickly shaded and outcompeted. Subterranean clover requires 120°Cd to reach 50% field emergence which is faster than the 145°Cd required for Italian ryegrass (Moot *et al.*, 2000). Italian ryegrass growth is also limited by soil moisture on the north slope. This resulted in the faster emergence of subterranean clover on the north slope allowing it to be able to compete more successfully with the Italian ryegrass.

There were more gorse seedlings on the south slope compared with the north slope (Figure 4.2). This could be due to higher levels of soil moisture resulting in higher germination and emergence. It was observed on the 18th August that the gorse seedlings on the north slope were starting to develop spines compared with the south slope that were still soft. Gorse seedlings have been shown to mature more slowly in environments with low light intensity (Bieniek and Millington, 1968). This is because shoot growth is slower which prevents spines from developing. The north slope is sunnier which results in the gorse seedlings maturing faster. There is also less shading of the gorse seedlings on the north slope as the Italian ryegrass population is lower.

5.4 Experiment 4: Herbicides

5.4.1 Gorse

Objective 4 was to determine the best herbicide to control the gorse seedlings emerging after the fire on the Port Hills. The glyphosate treatments caused the greatest damage to the gorse seedlings when applied in August (Table 4.7) and September (Table 4.10). This is expected as glyphosate has been shown to be very effective in controlling young gorse. For example, Lane and Park (1984) observed a 96% control of soft spine gorse 12 months after 0.54 kg a.i./100L of glyphosate was applied compared with 67% on hard spine gorse. This is thought to be due to more herbicide absorption occurring in soft spine gorse than at the more mature hard-spine stages. It is likely that over the next few months the gorse seedlings in the glyphosate treated plots will continue to die.

The herbicide treatments with saflufenacil took effect more quickly on the gorse seedling health, with effects noted in the first week after treatment, than the herbicides alone. The singular active chemical treatments, picloram, metsulfuron-methyl, triclopyr and glyphosate only began to show effects on the gorse seedlings in weeks 4 and 6 after application in August (Table 4.7). This indicates that saflufenacil is a fast acting herbicide. However, after six weeks the saflufenacil treatments showed no advantage to the singular herbicides. This result was consistent with that reported by Zabkiewicz *et al.* (2010) where the addition of saflufenacil to a triclopyr/picloram herbicide initially increased gorse brownout by 30% to 50% but after 337 days there was no difference in gorse control between saflufenacil and non-saflufenacil treatments. The same pattern was shown when saflufenacil was added to glyphosate and metsulfuron-methyl. The initial brown-out increased by 40-65% and 30% for saflufenacil/glyphosate and saflufenacil/metsulfuron-methyl treatments respectively after 28 days (Section 2.5.5). The quick effect of saflufenacil is likely due to the rapid mode of action as it inhibits protoporphyrinogen IX oxidase therefore inhibiting the tetrapyrrole biosynthetic pathway and photosynthesis (Grossmann et al, 2010). Thus, there would be no advantage in adding saflufenacil to herbicide treatments for the overall gorse control but it has an advantage when rapid knock down of seedlings is required.

Picloram and triclopyr were more effective when applied in September compared with August (Table 4.7 and 4.10). Picloram had an EWRS rating of 6.5 six weeks after application in August, compared with an EWRS rating of 7.5 four weeks after application in October. Triclopyr showed a similar trend. A more rapid result was observed after the September application as gorse seedlings grow faster in early spring than in winter (Ivens, 1978). Picloram and triclopyr are both pyridine derivative herbicides and therefore have a similar mode of action affecting auxin production (Section 2.5.1).

Terbuthylazine showed no effect on the gorse seedlings health during the six weeks after the August application (Table 4.7). However, when applied in September terbuthylazine significantly damaged the gorse seedlings with an EWRS of 8.5 (Table 4.10). The poor results from the August application was unexpected as terbuthylazine has been shown to kill 100% of gorse seedlings under 1.5 cm within 30 days in hydroponic studies (Zabkiewicz *et al*., 2010). In the hydroponic study gorse seedlings were suspended in herbicide solution. The initial ineffectiveness of terbuthylazine in the field could be due to the roots not being exposed to as much herbicide as they were in the hydroponic study. Terbuthylazine has been shown to be mostly root absorbed (Preest, 1980). It is possible that the roots were less active during late winter and therefore less terbuthylazine was taken up by the roots from the August application. In September, as the temperature increased, the gorse seedlings would have been growing more and therefore taking up more water with the roots and therefore more terbuthylazine.

This experiment has not been monitored long enough to examine the full effect of the herbicides on the gorse seedlings. It was noted that most gorse seedling treatments had green areas even after the 6 weeks of treatment. In previous studies, herbicide effects on gorse have been measured up to a year after application. Metsulfuron methyl has been reported to kill 95% of gorse seedlings of an unreported size after 10 months (Moore and Kennewell, 2010). Lane and Park (1984) reported 96% control of soft-spined gorse 12 months after the application of 0.54 kg a.i/100L glyphosate. Therefore, to get a more accurate estimation of herbicide performance of the herbicides on gorse seedlings health assessments should be continued beyond the time possible in this study.

The herbicides generally had a greater effect on the weeds than the gorse (Table 4.9). This could be due to the weeds growing faster than the gorse seedlings and therefore showing herbicide effects more quickly. As with the gorse, faster results were seen when the herbicides were applied in September (Table 4.12) compared with August. This is likely to similar reasons as the gorse.

5.4.2 Grass

Glyphosate resulted in the most damage to grass when applied in both August (Table 4.8) and September (Table 4.11). The significant grass damage by the glyphosate treatments was expected as glyphosate is broad spectrum herbicide that is thought to be effective on all higher plants (Duke & Powles, 2008). It was expected that metsulfuron-methyl would kill the grass as it has been shown to kill ryegrasses (James *et al.,* 1999). This did not occur with either application as metsulfuron-methyl has a slow action that inhibits root and shoot growth by inhibiting cell division (Brown, 1990) and the experiment did not run for long enough to see the full effects. Consistent with the gorse response, when saflufenacil was added to another herbicide damage was shown in the grass earlier likely due to the fast mode of action. This inhibition of photosynthesis by saflufenacil probably caused the grass damage at two and four weeks after application in August in the saflufenacil + triclopyr treatment, as triclopyr does not damage grass. The effect of saflufenacil had worn off by the 6^{th} week, allowing the grass to recover. Terbuthylazine showed no effect on grass health from the August application and only moderate effects when applied in September. This was likely due to the grass roots being more active in spring as terbuthylazine is root absorbed (Preest, 1980). Finlayson (1998) observed perennial ryegrass to have high tolerance to terbuthylazine.

6 GENERAL DISCUSSION AND CONCLUSIONS

6.1 General discussion

The Port Hills fire of February 2017 resulted in the removal of large areas of built up dead material in pastures and mature gorse stands. Following the burning of mature gorse bushes there was a flush of germination from gorse seed in the soil. The aim of this dissertation was to describe pasture regeneration of the burnt pasture areas and examine ways to control the emerging gorse seedlings.

6.2 Pasture area

Areas of pasture that had completely burnt had high levels of subterranean clover establishment. This was due to the fire removing dead material and then the heat from the fire increasing germination by breaking the hardseed. The removal of resident vegetation by fire could also have been achieved by recommended hard grazing in late summer. The fire effectively removed competition for light so the subterranean clover seedlings could establish. This trend continued through the experiment, with the botanical composition of the burnt areas having 26.5% subterranean clover compared with 4.0% subterranean clover in the unburnt pasture. This suggests that fire could be used as management strategy to increase subterranean clover emergence in unimproved pastures but alternative methods such as hard grazing would be environmentally more acceptable.

The Olsen P of the site was 5. The resident pasture was mostly browntop, which is very effective at taking up phosphorous, and therefore it is likely the subterranean clover was deficient for phosphorous. To retain the subterranean clover, the Olsen P should be raised by at least 10 units. The best way to do this would be by applying superphosphate fertilizer. The area should also be set stocked this spring to prevent the grasses growing too tall and outcompeting the subterranean clover. Grazing with cattle to a residual of around 12,000 kg DM/ha would also allow the annual subterranean clover to set seed this spring. Grazing hard through summer prior to subterranean clover germination next autumn will also increase emergence of new seedlings.

6.3 Burnt gorse area

Italian ryegrass competition has reduced the number of gorse seedlings by 52%. This is due to shading of the gorse seedlings and competition for water. Competition for water will increase as soil moisture decreases in summer, which may favour the ryegrass as they have a more extensive root system (Section 5.2). It is unlikely that using Italian ryegrass competition will eliminate the gorse population as gorse numbers are still high in the seeded plots. However, the gorse population is trending downwards and further monitoring is recommended in the following months. If ryegrass competition is going to be used to control gorse seedlings the pasture would ideally also be grazed. This is because multiple control methods are required to kill the majority of gorse seedlings. For example, grazing with goats or goats and sheep has been shown to reduce the gorse cover down to nearly 0% (Section 2.4.2). Furthermore, the wet but mild winter (Figure 3.1Figure 3.2) means there is now an estimated 5-6 t/ha of vegetation accumulated. This pasture should ideally be grazed, while it is still green to prevent the pasture drying off and creating a potential fire risk. Grazing should also be introduced as soon as possible while the gorse seedlings are still soft and palatable, especially if cattle are to be used.

If grazing cannot be used as a control, herbicides should be used to control the gorse seedlings. Picloram, triclopyr and terbuthylazine all gave acceptable control over the gorse seedlings without causing high damage to the Italian ryegrass. Glyphosate gave control over gorse seedlings but would also result in the death of the grasses and clover as well. This would result in no cover which would cause potentially result in erosion and the germination of new gorse seedlings. If terbuthylazine is to be used it needs to be applied before summer as it is only effective when the gorse seedlings are taking up water and still have soft spines (Section 5.4). Greater control of gorse seedlings will be achieved if the herbicide is applied this spring later as the gorse seedlings are starting to harden with spines on the north slope. This will make it herbicide absorption slower if it is foliage absorbed. Due to the Italian ryegrass being taller than the gorse seedlings, the gorse seedlings may not be covered in as much herbicide as in the experiment, as grass was cut down to expose the gorse seedlings. This may mean the herbicides are less effective on any plants below the canopy but should control the gorse seedlings in the areas of bare ground.

6.4 North and south aspects

The south slope had higher numbers of Italian ryegrass and gorse seedlings but lower numbers of subterranean clover compared with the north slope. This was due to higher soil moisture levels on the south slope which lead to favourable conditions for grass and gorse growth. This resulted in a decreased emergence of the less competitive subterranean clover.

In an ideal situation the two aspects would be subdivided and managed separately with white clover sown on the wetter south slope (Powers, 2007). The north face is drier and more suitable for subterranean clover. Subdivision of the two aspects would allow the north face to be managed correctly to allow seed set and germination of subterranean clover.

6.5 Managing a peri-urban environment

Lifestyle block owners often do not have the time, knowledge or infrastructure to properly manage the land they own. If management of pastoral areas on the Port Hills does not improve there will once again be a build up of dead material. This will dry out and become a fire risk. Landowners need support and education to prevent this from happening again. Local councils could also create regulation around pasture residues on properties in fire prone areas.

Gorse control is difficult but the fire has created an opportunity to reduce the gorse population on many areas of the Port Hills. Control methods, either biological or chemical, need to be introduced quickly while the gorse is still establishing as control of mature bushes is more difficult. Gorse control will have to be ongoing for many years due to the persistence of gorse seed in the soil but the current opportunity offers the greatest chance of success.

6.6 Recommendations for the next 12 months

As of November 2017, I would recommend grazing to be introduced immediately onto both the gorse and pasture areas. Cattle would graze soft seedlings but once seedlings harden goats would be the only option. Any gorse seedlings that mature and become too large to be controlled by grazing should be treated with herbicides that are effective on mature gorse, such as picloram (Section 2.5). Some areas that were missed when oversowing may need to be resown next autumn. The pasture area should also be grazed to clean up dead material in the unburnt pasture and to prevent dead material build up in burnt areas. The pasture area should be fertilizer to increase the Olsen P to retain the subterranean clover.

6.7 Conclusions

The following conclusion can be drawn, based off data collected in this dissertation:

1. The removal of dead material by fire led to higher numbers of subterranean clover seedlings and pasture growth than in unburnt areas.
2. Italian ryegrass competition reduced the number of gorse seedlings by 52% but there were still a high number of gorse seedlings which represents a sufficient population to re-establish the gorse bush area.
3. The south slope had higher amounts of Italian ryegrass and gorse seedlings and lower amounts of subterranean clover seedlings compared with the north slope due to differences in soil moisture and evapotranspiration.
4. Glyphosate was the most effective herbicide on the gorse seedlings at both application dates but also damaged grass seedlings. Terbuthylazine was effective at the later application date and only resulted in mild damage to the grass seedlings. Saflufenacil provided rapid results but ultimately was no more effective than the herbicides alone after four weeks.
5. The site should be grazed as soon as possible to control the gorse seedlings and to reduce the fire risk.

ACKNOWLEDGEMENTS

Firstly, I would like to acknowledge my supervisor Professor Derrick Moot for his support throughout the year and always encouraging me. I would not have been able to achieve this without his guidance

Thank you to David Schiel and Barbara Hayden for allowing me to conduct this work on your property.

To Keith Pollock, thank you for helping me with setting up the experiments and the field work. I learnt a lot from working with you.

Thank you to Malcom Smith and Dave Jack for applying the herbicides.

Thank you to my PLSC321 group for helping with the herbicide experiment and doing some pasture cuts.

To Mum, Dad and Caitlin, thank you for all your support over the past four years. Special thanks to Mum for helping me count seedlings.

Lastly, thank you to my partner Callum for not only helping me with data collection but for providing me with all the cups of tea necessary for me to finish writing this dissertation.

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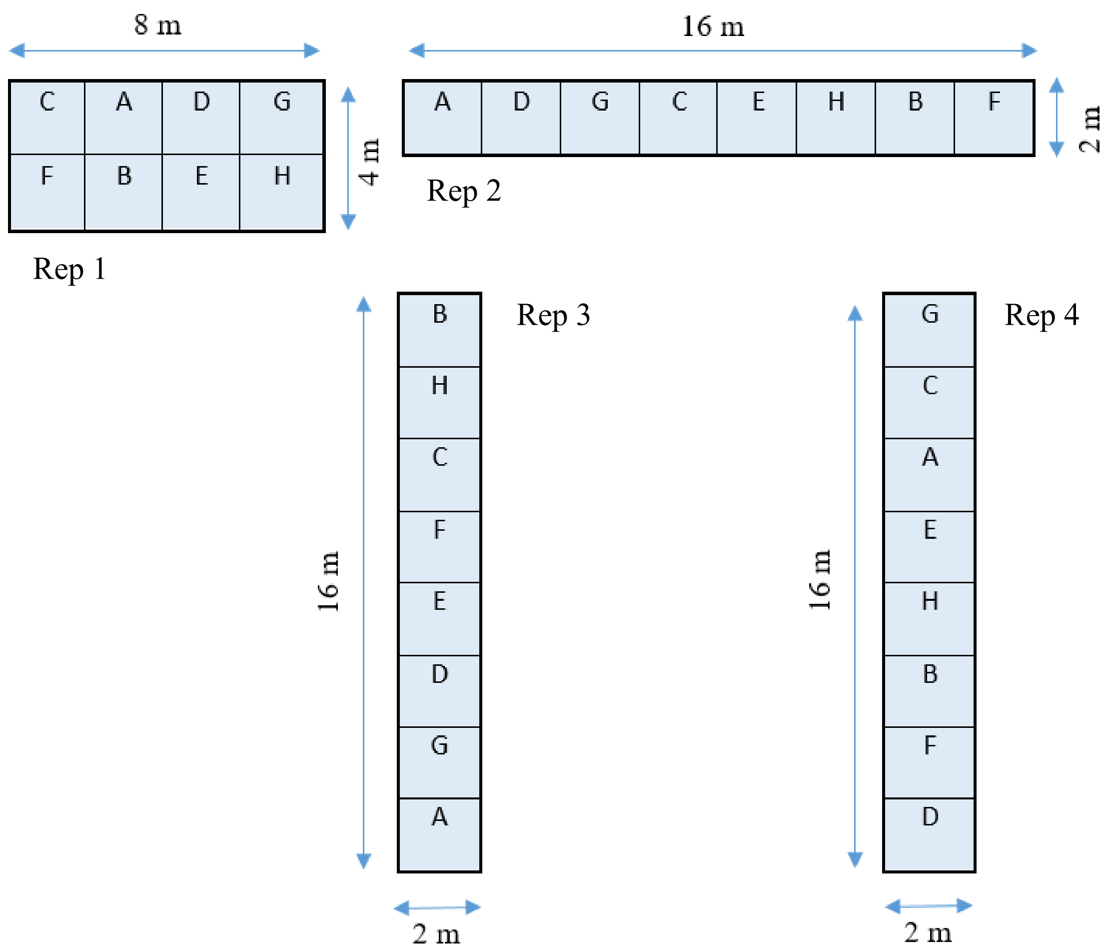
APPENDICES

Appendix 1 Treatment layout of the herbicides in Experiment 4 and dimensions of the plots

Top of the south slope of gorse gully



<u>Herbicide treatments</u>

A – Picloram, triclopyr, aminopyralid

B – Metsulfuron-methyl

C – Triclopyr

D – Terbuthylazine

E – Glyphosate

F – Saflufenacil + glyphosate

G – Saflufenacil + metsulfuron-methyl

H – Saflufenacil + triclopyr